THE COLLEGE OF AERONAUTICS

CRANFIELD

Characteristics of the High Temperature Mechanisms of Creep and Recovery in Graphite

Contract No. DA-91-591-E.U.C.2629
Quarterly Technical Status Report No. 2
November 1st 1962 - January 31st 1963

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Cranfield, Bletchley,
Buckinghamshire, England.

1. Statement of work carried out

The torsional creep apparatus described in an earlier report[1] has been calibrated and an initial series of tests completed. Although this series was intended primarily to gain operating experience on the rig, some results were obtained and are incorporated in this report. A second series on the same material (Morgan's E.Y.9 graphite), but over wider ranges of temperature and stress, is now in progress. The creep and recovery characteristics found on the graphitised material will be compared with the results to be obtained from another series in its ungraphitised form (C.Y.9). It is hoped to present the comparison in our next report.

The major stages in the calibration procedure are outlined below:-

a. Calibration of strain transducer

A special steel specimen, capable of free rotation and carrying a mirror, was connected to the transducer in an identical manner to that used for test specimens. The movement of a light spot reflected from the mirror on to a scale, divided in mm., placed 8 metres from the mirror was used to calibrate the transducer against specimen rotation. Tests were carried out to determine the optimum conditions of linearity and reproducibility of the transducer, and the calibration curve shown in Fig. 1 was obtained under these conditions. With the normal signal amplification used, the resolution obtained is $\pm 3 \times 10^{-5}$ degrees of rotation.

b. Calibration of Load Transducer

The deflection in the loading beam required to produce a measured elastic strain in a mild steel specimen was determined for a range of loads. The mild steel specimen was made to the dimensions shown in Fig. 2. By calculation from the dimensions of the specimen

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and from the strain transducer calibration above, the following equation can be obtained (see Appendix 1)

Applied Torque = $7.95 \times 10^2 \; \triangle V$

where $\triangle V$ is the voltage output of strain transducer under given conditions

The graph of the voltage output of the load transducer versus the applied torque is shown in Fig. 3. Experience with the first graphite series suggested that stiffer beams were required and these have now been fitted. A new calibration curve has been determined for use with beams on subsequent series.

c. Temperature Calibration

Fine wires of Zr, Cb, Ta, Mo and Nb have been obtained. It is proposed to correlate the accepted melting points of these metals with the indicated temperature of the creep rig at which these wires melt when placed in the normal specimen position.

d. Creep of Graphite E.Y.9 - Preliminary Series

A diagram of the specimen used is shown in Fig. 4. The gauge length is within the hot zone at the furnace centre. The upper tubular part of the specimen is subject to a loading of 43 per cent of the stress in the gauge length. In these results it has been assumed that all the creep occurred in the gauge length. Although this is not strictly accurate, all the specimens were identical and therefore comparisons between different loadings and temperatures are still possible. This ratio will be reduced in future series.

Creep curves are shown in Figs. 5 - 7. An anomaly, which will be investigated in the next series, is the increased creep at 2250° over that at either 2100° or 2350°. The apparent plateau in the creep strain from 20 - 70 minutes at 2100° may have been a real effect, or it may possibly be due to a fault in the measuring system although we have been unable to confirm such a fault up to the present. The question is still being investigated. No discussion is proposed here on these results, but will be given when more results are available from the second series.

Three creep recovery curves, obtained when the load was removed at some selected point during the creep test, are shown in Fig. 8. The rates of recovery, and the total recoverable proportion at the testing temperature, decrease with increasing temperature.

On cooling down from the testing temperature more recovery occurs, as detailed in Table 1. The method employed was to lower the temperature rapidly, allowing 30 seconds for the attainment of a stable temperature, the creep rate then being measured at this new temperature. As can be seen, the rate did not progressively decrease with temperature but showed a minimum at about 1900°C. When cold, the specimen had apparently recovered the original creep strain almost completely. An apparent strain is developed on heating an unstrained specimen from cold to 2000°C, but this is only about .01°/in., which is far less than the recovery on cooling. The so-called 'plastic' component of creep strain is, therefore, recoverable.

All the above points will be fully investigated in the next series on E.Y.9 and the results presented in our next report (G.T.S.R. No. 3).

2. Research Plans

These broadly remain as originally proposed. As stated above, the next series involves a comparison of the creep and recovery characteristics of a carbon and the graphite produced from it. Arrangements are being made for the production of some special graphites.

3. Personnel, Administrative Actions, Conferences, etc.

The personnel engaged on this work remained the same. About 400 man-hours were contributed by the College Workshop.

Dr. Younger attended a one-day course on the Analysis of Creep Results at the National Gas Turbine Establishment on 30th November, 1962.

4. Utilisation of Funds

These have been fully utilised.

5. Important Property Acquired

None.

6. Miscellaneous

It is proposed to submit the results of our work to the 6th Biennial Carbon Conference in Pittsburgh, Pa., next June, and that Dr. Younger may attend to present the paper.

APPENDIX 1

Calculations involved in the load calibration

For any shaft, the angle of twist, Θ, is given by

$$\Theta = \frac{Tl}{NJ}$$

where T is the applied torque
l the length of shaft
J its polar moment of inertia
N the modulus of the shaft material.

For a tube

$$J = \frac{\pi}{32}(D^4 - d^4)$$

where D and d are the external and internal diameters respectively.

For this steel specimen:

$$\Theta = \frac{T}{N}\left(\frac{l_1}{J_1} + \frac{l_2}{J_2} + \frac{l_3}{J_3}\right)$$

where l_1 is the distance between the centre line of the upper pin and the gauge length,
l_2 is the gauge length, and
l_3 the distance between the gauge length and the centre line of the strain transducer arm.
J_1, J_2 and J_3 are the respective polar moments of inertia.

Substituting actual values, we have

$$\Theta = \frac{32T}{\pi N}\left\{\frac{2.25}{0.687} + \frac{3.00}{0.0608} + \frac{8.562}{1}\right\}$$

and hence

$$\Theta = \frac{626T}{N}$$

If N for mild steel is taken as 11.54×10^6 p.s.i.,

then $\Theta_{rad} = \frac{626 \times T}{11.54 \times 10^6}$, where T is in lb.-in.

or

$$T = \frac{\Theta^o}{3.1} \times 10^3$$

But from the strain transducer calibration, a specimen twist of 1^{o} would produce a voltage change of 0.406V. Therefore, the applied torque to the steel specimen may be measured in terms of the voltage change on the strain transducer by means of the relationship

$$T = \frac{10^3}{3.1 \times 0.406} \Delta V \text{ lb.-in.}$$

where ΔV is the voltage change at the set conditions

Hence

$$T = 7.95 \times 10^2 \Delta V \text{ lb.-in.}$$

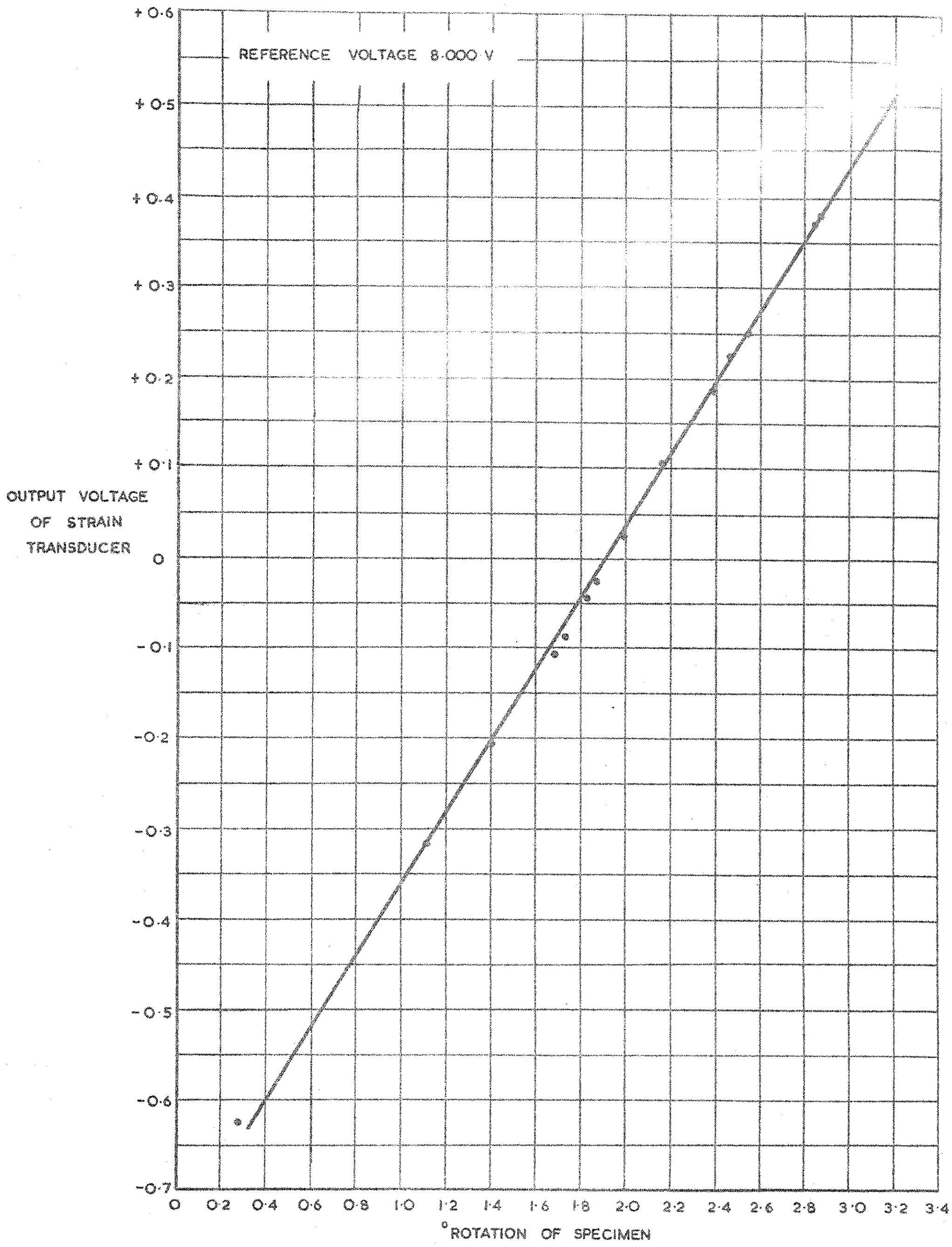
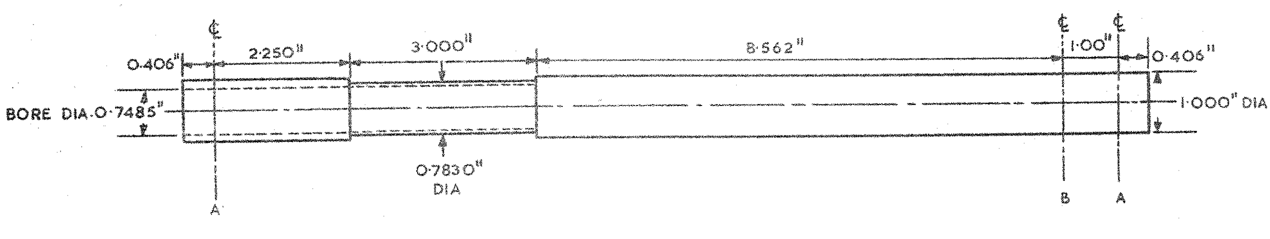


FIG. 1. OUTPUT VOLTAGE OF STRAIN TRANSDUCER VS. ROTATION OF SPECIMEN.



A = CENTRE-LINE OF HOLES 0·250" DIA FOR LOADING PINS.

B = CENTRE-LINE OF HOLE 0·125" DIA FOR STRAIN-TRANSDUCER ARM.

FIG. 2. STEEL CALIBRATION SPECIMEN.

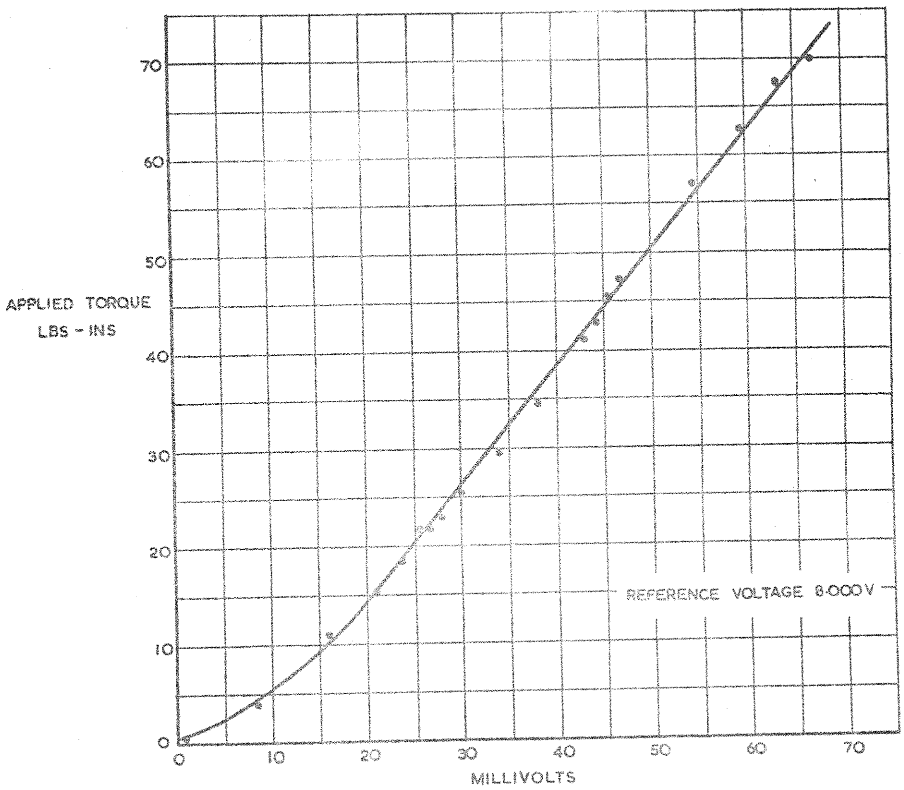
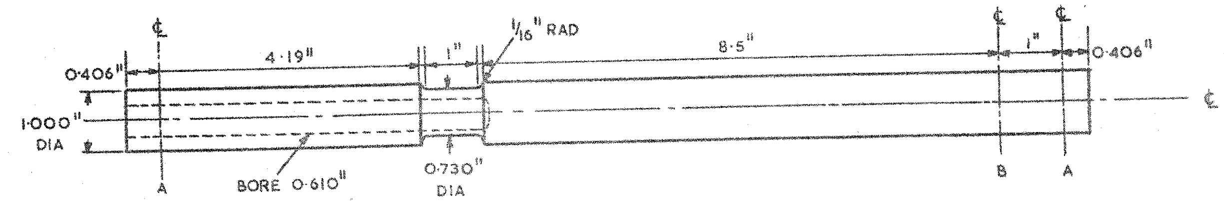


FIG. 3. TORQUE APPLIED TO STEEL SPECIMEN VS. VOLTAGE CHANGE OF LOAD TRANSDUCER.



A – 0·250" HOLE FOR LOADING PINS

B – 0·125" HOLE FOR STRAIN TRANSDUCER ARM.

FIG. 4. GRAPHITE SPECIMEN USED IN THIS SERIES.

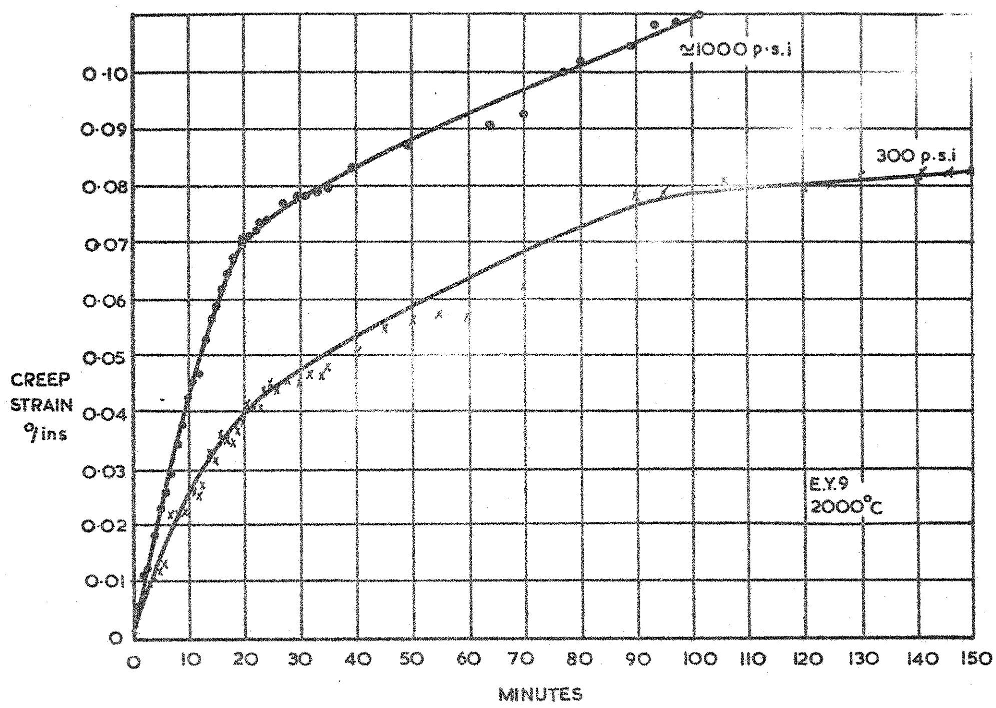


FIG.5. CREEP OF E.Y.9. AT 2000°C.

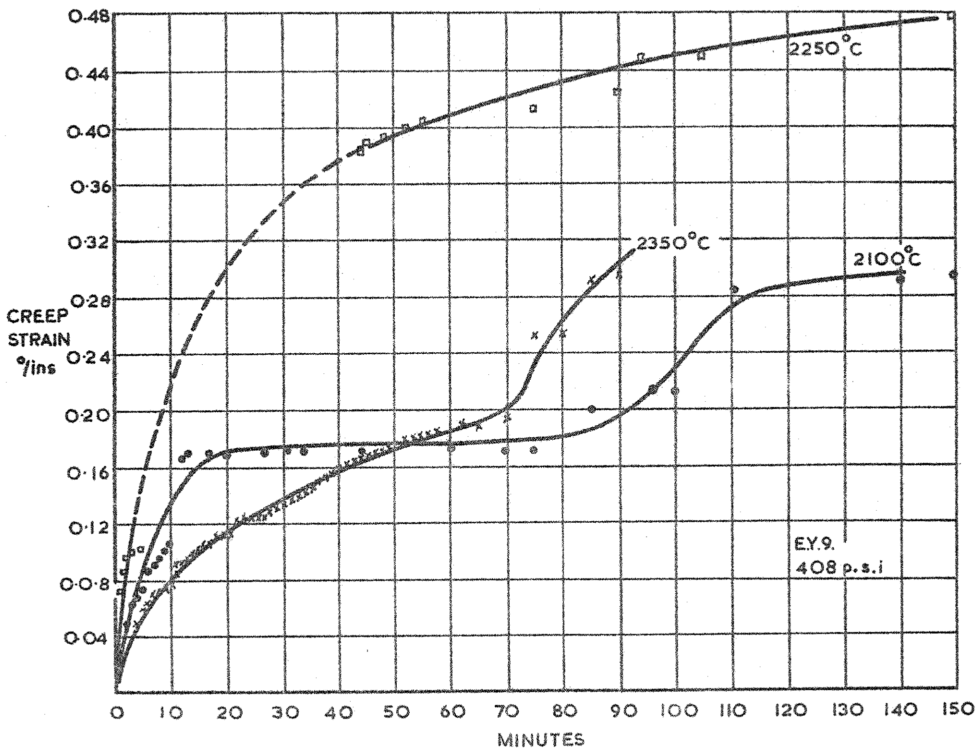


FIG.6. CREEP OF E.Y.9. AT A RANGE OF TEMPERATURES FOR A CONSTANT STRESS.

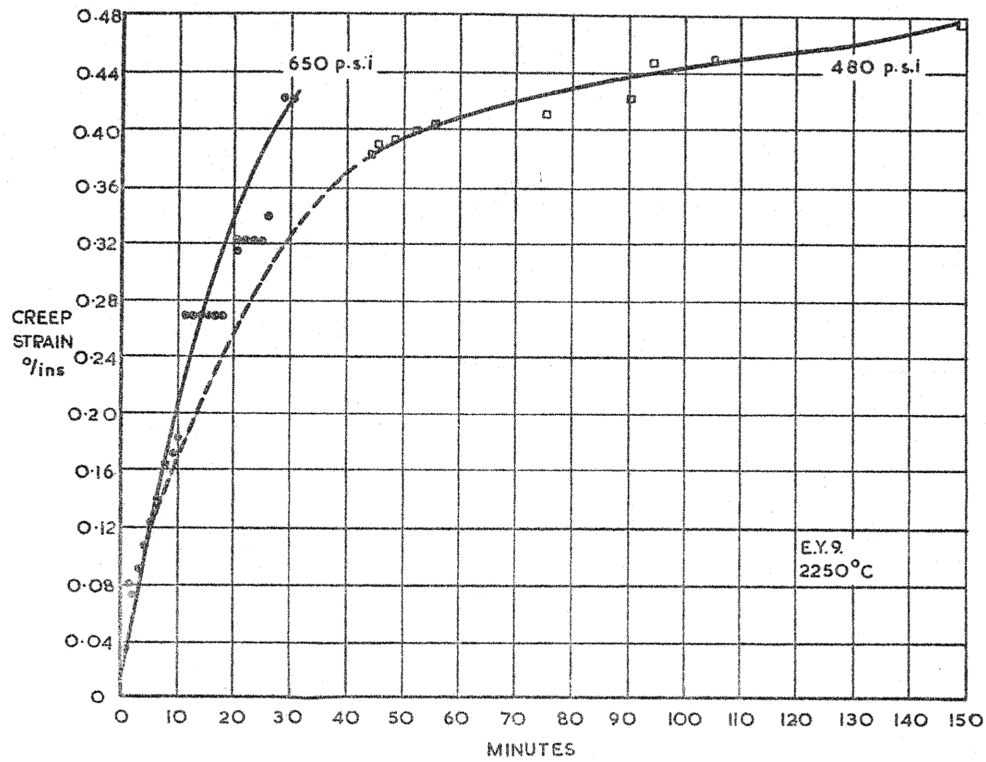


FIG.7. CREEP OF E.Y.9. 2250°C.

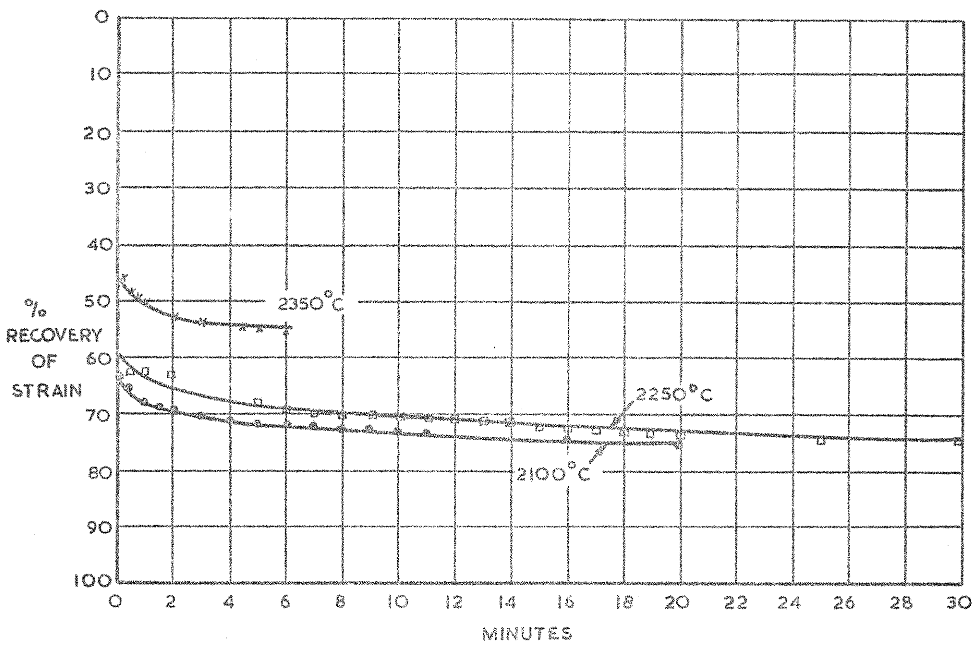


FIG.8. RECOVERY OF E.Y.9. AFTER CREEP.

TABLE 1 - Recovery on Cooling

Temperature of Creep Test	2350°C.		2250°C.		2100°C.	
Total strain at end of creep °/in.	0.703		1.29		0.29	
Per cent of above strain due to creep	32		32.6		32.6	
Rate of recovery in last minute at creep temperature %/min.	1.0		0.06		0.025	
Total recovery at creep temperature %	52.2		74.2		74.6	
	A	B	A	B	A	B
at 2200°C	58.1	1.8				
at 2150°C			74.6	-		
at 2100°C	61.9	1.1				
at 2050°C			75.1	0.5		
at 2000°C	64.5	0.9			74.8	0.5
at 1950°C			76.6	0.4		
at 1900°C	66.4	0.3			75.4	0.2
at 1840°C			77.7	0.3		
at 1800°C	67.4	0.2			75.7	0.7
at 1750°C			78.5	-		
at 1700°C	68.6	0.3			76.8	0.6
at 1650°C			79.2	0.2		
at 1600°C	69.9	0.7			78.0	0.6
at 1550°C			79.7	-		
at 1500°C	70.7	0.6			78.9	0.6
Total recovery when cold	98.5%		92.4%		95.2%	

A - Total per cent recovery on lowering to the given temperature

B - Amount (as a percentage) of recovery in first minute at the given temperature