C.P. No. 945

C.P. No. 945

MINISTRY OF TECHNOLOGY

AERONAUTICAL RESEARCH COUNCIL

CURRENT PAPERS

A Convenient Representation of Creep Strain for Problems Involving Time-varying Stresses and Temperatures

By

J. M. Clarke

LONDON: HER MAJESTY'S STATIONERY OFFICE

1967

FIVE SHILLINGS NET

U.D.C. No. 539.434:539.319

C.P. No. 945*
September 1966

A convenient representation of creep strain data for problems involving time-varying stresses and temperatures

- by -

J. M. Clarke

SUMMARY

An empirical approach to the representation of observed creep strain behaviour for a wide range of times, stresses and temperatures is outlined. The formulae are unusual in permitting the representation of primary and tertiary creep behaviour without forfeiting the convenience of explicit expressions for the strain rate using either the strain or time hardening hypotheses. They are therefore particularly suited for use in stress redistribution calculations.

A comparison is made between the usual expressions for stress dependence. A table lists the arbitrary constants chosen to fit the creep behaviour of the Nimonic alloys 80A, 90, 100 and 105.

*Replaces N.G.T.E. R.284 - A.R.C. 28481

CONTENTS

		Page
1.0	Introduction	4
2.0	Use of a hyperbola to represent log(creep strain) versus log(time) results	4
3.0	Variation with stress and temperature	4
4.0	Cartesian and parametric forms for a hyperbola in terms of θ, ϕ and A	5
5.0	A comparison of some formulae for describing the stress dependence of the time scale	8
6.0	The calculation of creep strain rates	8
	6.1 Time hardening hypothesis	9
	6.2 Strain hardening hypothesis	9
	6.3 Parametric hardening hypothesis	10
7.0	Comment	10
8.0	Conclusion	10
Acknowledgments		10
References		11
Detachable Abstract Cards		

TABLES

No.	Title	
I	Creep properties of some Nimonic alloys	12
II	Units	13

APPENDICES

No.	Title	
I	Notation	14
II	Numerical example	15

ILLUSTRATIONS

Fig. No.	Title
1	Typical creep results
2	Typical logarithmic creep curve fitted with a hyperbola
3	Stress and temperature variation of time scale
4	Stress and temperature variation of strain scale
5	Temperature variation of time scale - zero stress intercept (D)
6	Temperature variation of time scale - stress derivative (E)
7	Stress dependence formulae - a comparison
8	Strain, parametric and time hardening hypotheses contrasted

1.0 Introduction

This Report describes a method used at N.C.T.E. for the reduction of an experimentally obtained set of creep strain values over a range of stresses, temperatures and times into empirical formulae which are particularly suitable for use in stress redistribution calculations. The formulae have the property of allowing either time or strain to be derived explicitly from the other three variables while permitting the representation of both decelerating and accelerating creep rates. This feature permits time and strain hardening hypotheses† to be used without successive approximations. The constants by which the creep properties can be represented are obtained by simple geometric means.

The methods described have a value pertinent particularly to the numerical solution of creep problems involving time-varying stresses and temperatures, but are not presumed or intended to throw any new light on the fundamental nature of creep processes.

2.0 Use of a hyperbola to represent log(creep strain) versus log(time) results

Creep tests during which the stresses and temperatures are maintained constant show considerable similarities in the shapes (to some scales) of the strain versus time curves for widely different values of stress and temperature[1]. A typical set of results[3] for Nimonic 90 is shown in Figure 1. The shape of the curve fitted to these results has propagated the widespread use of the terms 'primary', 'secondary' and 'tertiary' to describe the periods of decreasing, constant and increasing strain rates. Because the strain versus time results cover a large range of strain and time it is convenient to plot the results in the form log(creep strain) versus log(time). Figure 2 shows the same results plotted in terms of natural logarithms. The shape of the curve is typical for all the alloys of the Nimonic series and in this Report it is assumed that it can be adequately described by a hyperbola such as the one drawn on Figure 2.

The general hyperbola requires the specification of five independent parameters. Three of these parameters can define its shape while the other two determine its position. The variation of these parameters with stress and temperature is discussed in the next section.

3.0 Variation with stress and temperature

Examination of the results of creep tests on Nimonic alloys 80, 90 and 100 (Reference 1) shows that the shape of the hyperbola (described for example by the values of θ, ϕ and A shown on Figure 2) remains substantially unchanged for a wide range of values of stress and temperature. On the other hand its position with respect to both ln(strain) and ln(time) scales does vary. The position can conveniently be defined by the values of strain (λ) and time (τ) at the interception of the hyperbola's asymptotes.

†Section 6.0 considers the calculation of strain rates using these hypotheses

Figures 3 and 4 show the variation of $\ln(\tau)$ and $\ln(\lambda)$ for one cast of Nimonic 90. It is evident that a straight line stress dependence emerges in both cases. Temperature influences both the slope and level of the lines for $\ln(\tau)$ but no systematic temperature variation is evident from the $\ln(\lambda)$ results. These results are typical for all the Nimonic series alloys for which the creep properties have been analysed in this way.

The stress (σ) and temperature (T) variation of the creep strain results can therefore be represented within the normal experimental range by

$$\lambda = \exp\left\{B + C.\sigma\right\} \qquad ....(1)$$

$$\tau = \exp\left\{D + E.\sigma\right\} \qquad ....(2)$$

where B and C are constants but D and E are temperature dependent.

Table I summarises the creep properties of Nimonic alloys 80*, 90*, 100 and 105 by giving appropriate values to θ, ϕ, A, B and C and values to D and E at all the experimental temperatures. Figures 5 and 6 illustrate the temperature dependence of D and E, and show that fairly simple expressions could be used to represent this dependence if they happened to be more convenient than tabulated values for some particular calculations.

4.0 Cartesian and parametric forms for a hyperbola in terms of θ, ϕ and A

A hyperbolic relation between ln(creep strain) and ln(time) may be described in general terms by

$$l.\ln^2\left(\frac{t}{\tau}\right) + m.\ln^2\left(\frac{\varepsilon}{\lambda}\right) + n.\ln\left(\frac{t}{\tau}\right).\ln\left(\frac{\varepsilon}{\lambda}\right) = A^2 \qquad ....(3)$$

where t and ε are time and creep strain respectively and τ, λ and A have the meanings shown on Figure 2. For convenience the co-ordinates x and y are introduced, defined by

$$x = \ln\left(\frac{t}{\tau}\right) \qquad ....(4)$$

$$y = \ln\left(\frac{\varepsilon}{\lambda}\right) \qquad ....(5)$$

They have their origin at $t = \tau$, $\varepsilon = \lambda$.

*Henry Wiggin and Company have remarked that the data for these alloys is old and that their current production has a significantly improved creep resistance.

It can be shown geometrically that the coefficients l, m and n are related to the gradients of the asymptotes (θ and ϕ) by the formulae:

$$\left.\begin{aligned} l &= \sin^2\left(\frac{\phi + \theta}{2}\right) - \cos^2\left(\frac{\phi + \theta}{2}\right) \tan^2\left(\frac{\phi - \theta}{2}\right) \\ m &= \cos^2\left(\frac{\phi + \theta}{2}\right) - \sin^2\left(\frac{\phi + \theta}{2}\right) \tan^2\left(\frac{\phi - \theta}{2}\right) \\ n &= -\sin(\theta + \phi)\ \sec^2\left(\frac{\phi - \theta}{2}\right) \end{aligned}\right\} \quad \ldots.(6)$$

Alternatively the same hyperbola as given by Equation (3) may be expressed in the parametric form

$$\left.\begin{aligned} \ln\left(\frac{t}{\tau}\right) &= pA \sinh\,(z - r) \\ \ln\left(\frac{\varepsilon}{\lambda}\right) &= qA \sinh\,(z + s) \end{aligned}\right\} \quad \ldots.(7)$$

where the coefficients p, q, r and s depend on the gradients of the asymptotes as given by the formulae:

$$\left.\begin{aligned} \cosh\,(r) &= \left(1 - \tan^2\left(\frac{\phi + \theta}{2}\right) \tan^2\left(\frac{\phi - \theta}{2}\right)\right)^{-\frac{1}{2}} \\ \cosh\,(s) &= \left(1 - \tan^2\left(\frac{\phi - \theta}{2}\right)\Big/\tan^2\left(\frac{\phi + \theta}{2}\right)\right)^{-\frac{1}{2}} \\ p &= \cos\left(\frac{\theta + \phi}{2}\right)\Bigg/\left(\tan\left(\frac{\phi - \theta}{2}\right) \cosh\,(r)\right) \\ q &= \sin\left(\frac{\theta + \phi}{2}\right)\Bigg/\left(\tan\left(\frac{\phi - \theta}{2}\right) \cosh\,(s)\right) \end{aligned}\right\} \quad \ldots.(8)$$

and the parameter z changes from $-\infty$ when x and y approach $-\infty$ to $+\infty$ when x and y approach $+\infty$. The closest approach to the origin is when $z = 0$ and then $x^2 + y^2 = A^2$ and $x/y = -\tan\left(\frac{\theta + \phi}{2}\right)$.

A special case of the above formulae, which is important since it is often observed and is symmetrical in x and y, corresponds to 'primary' and 'tertiary' time exponents of $\frac{1}{3}$ and 3. For this case

$$\theta = \arctan \tfrac{1}{3} \approx 18{\cdot}5^{\circ}$$

and

$$\phi = \arctan 3 \approx 71{\cdot}5^{\circ}$$

so that Equation (3) becomes

$$3 \ln^2 \frac{t}{\tau} + 3 \ln^2 \frac{\varepsilon}{\lambda} - 10 \ln \frac{t}{\tau} . \ln \frac{\varepsilon}{\lambda} = 8A^2 \qquad \ldots.(9)$$

and Equation (7) becomes

$$\left.\begin{aligned} \ln\left(\frac{t}{\tau}\right) &= \sqrt{\frac{3}{2}}\, A \sinh\,(z - 0{\cdot}55) \\ \ln\left(\frac{\varepsilon}{\lambda}\right) &= \sqrt{\frac{3}{2}}\, A \sinh\,(z + 0{\cdot}55) \end{aligned}\right\} \qquad \ldots.(10)$$

The usefulness of the hyperbolic representation arises from the simplicity with which values for θ, ϕ and A can be chosen from experimental results and the ease with which Equation (3) can be solved from given values of strain or time. Equation (3) can be regarded as a quadratic in either x or y leading to the solutions

$$y = \frac{1}{2.m}\left(- nx + \left((n^2 - 4.lm)x^2 + 4.mA^2\right)^{\frac{1}{2}}\right) \qquad \ldots.(11)$$

$$x = \frac{1}{2.l}\left(- ny - \left((n^2 - 4.lm)y^2 + 4.lA^2\right)^{\frac{1}{2}}\right) \qquad \ldots.(12)$$

A numerical example illustrating the use of the above formulae for the evaluation of the time to 0·2 per cent creep strain of Nimonic 90 at 815°C and 10 ton/in² is given in Appendix II.

5.0 A comparison of some formulae for describing the stress dependence of the time scale

Equations (1) and (2) imply finite values for λ and τ when the stress (σ) is zero and their use therefore leads to the questionable conclusion that finite creep strains take place even when $\sigma \to o$! This situation can be avoided if Equation (2) is extended to

$$\left.\begin{aligned} \frac{1}{\tau} &= \exp\left\{-D - E.\sigma\right\}, \quad \sigma \geqslant -\frac{1}{E} \\ \frac{1}{\tau} &= -E.\sigma \exp\left\{1 - D\right\}, \quad \sigma \leqslant -\frac{1}{E} \end{aligned}\right\} \qquad \ldots.(13)$$

where the expression chosen for the low stress values is linear in stress (as for viscous flow) while the two expressions are continuous and have a continuous stress derivative at $\sigma = -\frac{1}{E}$.

Alternative expressions summarised elsewhere[6] and also containing two arbitrary constants are

$$\frac{1}{\tau} = F \sinh (G\sigma) \qquad \ldots.(14)$$

and

$$\frac{1}{\tau} = H\sigma^4 + J\sigma^8 \qquad \ldots.(15)$$

where F, G, H and J are the arbitrary constants.

Figure 7 shows Equations (13), (14) and (15) fitted to the same experimental data. It can be seen that all three formulae give a reasonable representation of the experimental results and that Equations (13) and (14) are almost identical. A disadvantage of Equation (15) is that other stress exponents are required at other temperatures so that a more widely applicable formula of this type generally needs more than two constants.

6.0 The calculation of creep strain rates

In order to calculate creep strain rates some extensions of the above formulae will now be given. It follows from the definitions of x and y in Equations (4) and (5) that the creep strain rate is given by

$$\frac{d\varepsilon}{dt} = \frac{dy}{dx} \cdot \frac{\varepsilon}{t} \qquad \text{....(16)}$$

The gradient $\frac{dy}{dx}$ of the hyperbola is most easily obtained by implicit differentiation of Equation (3); then Equation (16) can be written

$$\frac{d\varepsilon}{dt} = -\frac{2.lx + ny}{2.my + nx} \cdot \frac{\varepsilon}{t} \qquad \text{....(17)}$$

Alternatively the gradient may be expressed in terms of the parameter z by differentiation of Equation (7) and Equation (16) can then be written

$$\frac{d\varepsilon}{dt} = \frac{q \cosh(z + s)}{p \cosh(z - r)} \cdot \frac{\varepsilon}{t} \qquad \text{....(18)}$$

The creep test results to which the formulae have been fitted were obtained at constant stress (sometimes constant load) and temperature. In order to estimate a strain rate after a change in either of these variables it is necessary to specify at least one other which represents the influence of previous loading history. Since this third variable represents the accumulation of effects from previous loading it should remain unchanged during any rapid (ideally instantaneous) change in stress or temperature.

The calculation of strain rates from the creep formulae using stress, temperature and either time (time hardening hypothesis) or strain (strain hardening hypothesis) or 'z' (parametric hardening hypothesis) as the history dependent variable is now described.

It is assumed in the procedures which follow that the values of l, m, n, p, q, r and s are already available. Because they depend only on the slopes of the asymptotes they do not generally change with stress or temperature.

6.1 Time hardening hypothesis

Given σ, T and t, the variables λ, τ and x are obtainable from Equations (1), (2) and (4). Equation (11) then gives y from x and Equation (5) gives ε from y. The variables x, y, t and ε are then available for substitution into Equation (17) for strain rate.

6.2 Strain hardening hypothesis

Given σ, T and ε, the variables λ, τ and y are obtainable from Equations (1), (2) and (5). Equation (12) then gives x and y and Equation (4) then gives t from x. The variables x, y, t and ε are then available for substitution into Equation (17) for strain rate.

6.3 Parametric hardening hypothesis

This hypothesis follows directly from the uniform shape observed for the ln(creep strain) versus ln(time) curves, which are merely displaced for different stresses and temperatures. Figure 8 shows two such curves. The points P_1, P_2 and P_3 on the new curve have the same values of strain, parameter and time respectively as the point P_0 on the old curve. It will be noticed that if the constant C in Equation (1) is zero then all displacements are parallel to the time axis and the strain and parametric laws coincide. For positive values of C the parametric hypothesis implies strain rates intermediate between those of the time and strain hardening hypotheses. In this connection it has been observed by Johnson[7] that for some materials the most satisfactory description of variable stress effects with increasing stress requires a compromise between strain and time hardening.

Given σ, T and z, the variables λ, τ, x and y can be found from Equations (1), (2) and (7). The values of t and ε follow from Equations (4) and (5) so that z, ε and t are available for substitution into Equation (18) for the strain rate.

7.0 Comment

The use of empiricism to describe experimental results inevitably requires some compromise between complexity and accuracy. The particular method described in this Report has been found to be accurate for the Nimonic series of alloys while being particularly suitable for stress redistribution calculations. The author has no reason to believe that it would not be equally satisfactory for other alloys but has had no experience with them.

8.0 Conclusion

The creep strain behaviour of several Nimonic alloys is concisely represented by the numerical data in Table I together with the following formulae:

$$3x^2 + 3y^2 - 10xy = 8A^2 \qquad \text{....(19)}$$

where

$$x = \ln t - D - E.\sigma \qquad \text{....(20)}$$

$$y = \ln \varepsilon - B - C.\sigma \qquad \text{....(21)}$$

The numerical values in Equation (19) arise from 'primary' and 'tertiary' time exponents of $\frac{1}{3}$ and 3 respectively; different exponents can be introduced using Equations (3) and (6).

ACKNOWLEDGMENTS

The author gratefully acknowledges the Nimonic alloy 105 creep data communicated by Henry Wiggin and Company Limited and Rolls-Royce Limited.

REFERENCES

No.	Author(s)	Title, etc.
1	K. F. A. Walles	A quantitative presentation of the creep of Nimonic alloys A.R.C. 20935 March 1959
2	R. W. Ridley B. S. W. Mann G. R. Tremain	The creep properties of Nimonic 80A at 700°C, 750°C and 815°C, and the fatigue properties at 750°C for periods up to 2000 hours N.P.L. Engineering Division No. 477/51
3	R. W. Ridley B. S. W. Mann G. R. Tremain	The creep and fatigue properties of Nimonic 90 at 700°C, 750°C and 815°C. N.P.L. High Temperature Mechanical Properties Section HT.3/51
4	J. Buchan	Private communication on behalf of Henry Wiggin and Company Limited
5	S. G. Baker	Private communication Rolls-Royce Limited
6	A. J. Kennedy	Processes of creep and fatigue in metals Oliver and Boyd, 1962, p.153
7	A. E. Johnson J. Henderson V. Mathur	Creep under changing complex stress systems The Engineer, p.209, Vol. 206, 1958

TABLE I

Creep properties of some Nimonic alloys

Nimonic alloy No.	θ*	φ*	A*	B*	C*	Temp.	D*	E*
80A≠ Reference 2	18.5°	71.5°	0.35	- 7.88	0.055	700°C	12.25	-0.282
						750°C	10.37	-0.318
						815°C	9.15	-0.442
90≠ Reference 3	18.5°	71.5°	0.40	- 8.00	0.065	700°C	15.00	-0.375
						750°C	12.00	-0.350
						815°C	10.20	-0.457
90≠ Reference 1	18.5°	71.5°	0.60	- 7.44	0.050	650°C	16.12	-0.338
						700°C	13.50	-0.330
						750°C	11.75	-0.375
						815°C	9.87	-0.493
						870°C	8.85	-0.760
100 Reference 1	18.5°	71.5°	1.05	- 7.00	0	700°C	15.70	-0.320
						750°C	14.25	-0.350
						815°C	13.35	-0.515
						870°C	10.80	-0.560
						940°C	10.60	-1.260
105 Reference 4	26.0°	79.0°	0.92	- 5.90	0.020	750°C	15.00	-0.360
						815°C	12.80	-0.430
						870°C	10.60	-0.520
						980°C	8.40	-1.000
	(26.0°	79.0°	0.92	-11.94	0.140	650°C	12.60	-0.158)†
105 Reference 5 (Rolls-Royce heat treatment)	18.5°	71.5°	0.64	- 5.54	0	577°C	19.90	-0.234
						800°C	12.90	-0.400
						975°C	8.10	-0.970
						1100°C	6.45	-3.750

*Refer to Table II for units.

†These results for alloy 105 at 650°C did not fit the normal patterns. The tests involved used a slightly smaller size of specimen than those used for the other temperatures.

≠The data from these references are old and current production batches have a significantly improved creep resistance.

TABLE II

Units

Symbol	Units
θ	Angle in degrees of arc
ϕ	Angle in degrees of arc
A	Natural logarithm cycles
B	Natural logarithm cycles
C	Natural logarithm cycles/(ton/in^2)
D	Natural logarithm cycles of hr
E	Natural logarithm cycles of hr/(ton/in^2)

APPENDIX I

Notation

A	shortest distance from the hyperbola to the point of intersection of its asymptotes
B, C	constants describing the stress dependence of the strain scale
D, E	temperature dependent variables describing the stress dependence of the time scale
F, G, H, J	arbitrary constants used in formulae for stress dependence
l, m, n, p, q, r, s	variables dependent on the gradients of the hyperbola's asymptotes
P_r	positions on Figure 8 distinguished by the subscript
t	time
x, y	co-ordinates on ln(strain) - ln(time) plane
z	parameter of the hyperbola
ε	creep strain
θ, ϕ	angles between hyperbola asymptotes and x direction
λ	a reference strain
σ	stress
τ	a reference time

APPENDIX II

Numerical example

To find the time to 0·2 per cent creep strain at 815°C, 10 ton/in² for Nimonic alloy 90.

Table I gives the necessary creep constants at 815°C for Nimonic 90 (data from Reference 3) so that interpolations from Figures 5 and 6 are not required.

Equations (1) and (2) become

$$\ln(\lambda) = -8{\cdot}00 + 0{\cdot}065 \times 10 = -7{\cdot}35$$

and

$$\ln(\tau) = 10{\cdot}20 - 0{\cdot}457 \times 10 = 5{\cdot}63$$

For 0·2 per cent creep strain we have from Equation (5)

$$y = \ln(0{\cdot}002) - \ln(\lambda)$$

$$= -6{\cdot}21 + 7{\cdot}35 = 1{\cdot}14$$

Since $\theta = 18{\cdot}5^{\circ}$ and $\phi = 71{\cdot}5^{\circ}$, Equation (9) applies and Equation (12) becomes

$$x = \tfrac{1}{6}\left(10y - \left(64y^2 + 96A^2\right)^{\frac{1}{2}}\right)$$

Now $A = 0{\cdot}4$ so that, substituting for y and A,

$$x = \tfrac{1}{6}\,(11{\cdot}4 - 9{\cdot}4) = 0{\cdot}33$$

Finally from Equation (4)

$$\ln(t) = x + \ln(\tau)$$

$$= 5{\cdot}96$$

$$\therefore \quad \log_{10}(t) = \frac{5{\cdot}96}{2{\cdot}30} = 2{\cdot}59$$

$$\therefore \quad \underline{t = 390 \text{ hr}}$$

FIG. 1

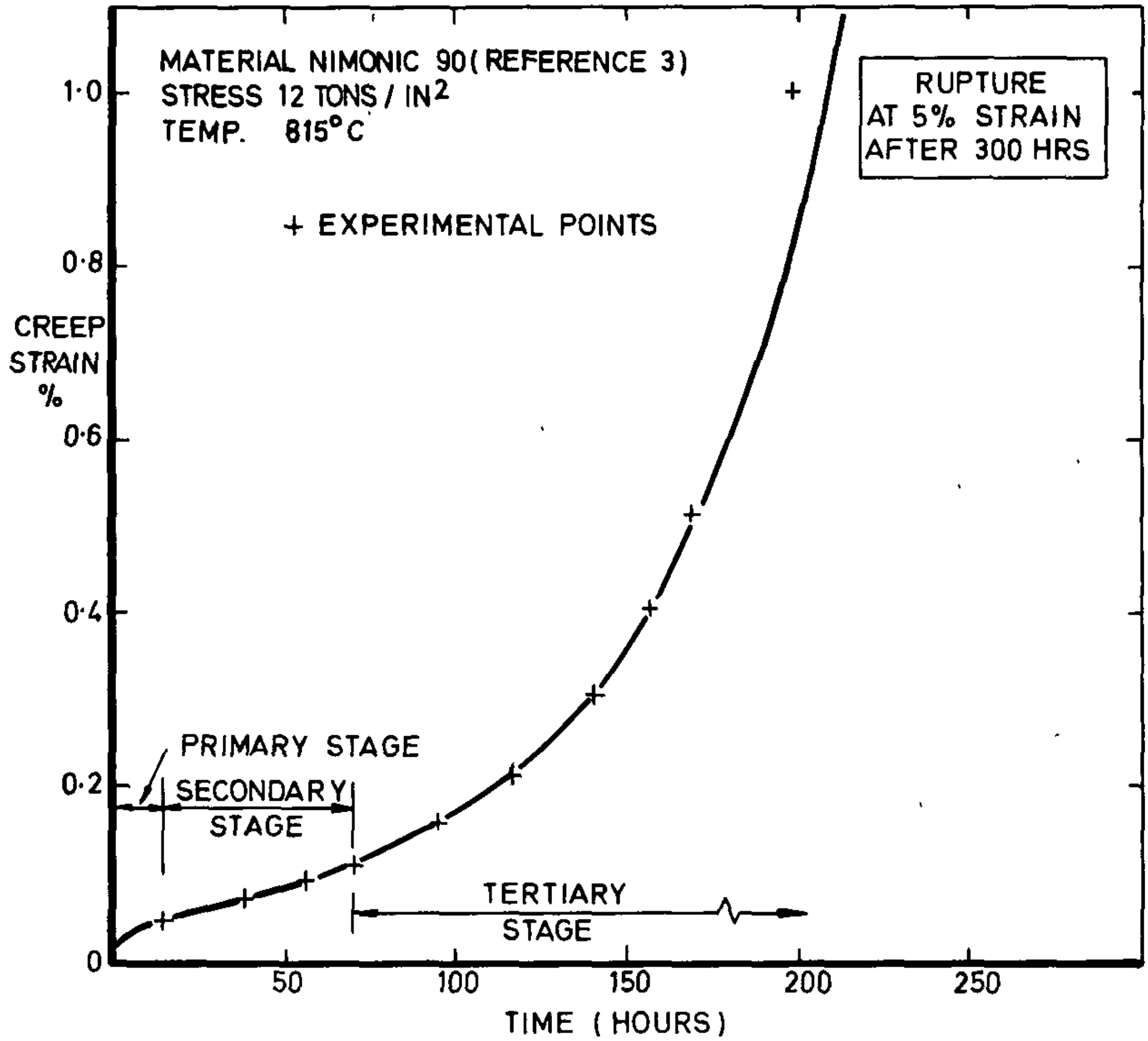

FIG. I. TYPICAL CREEP RESULTS

FIG. 2

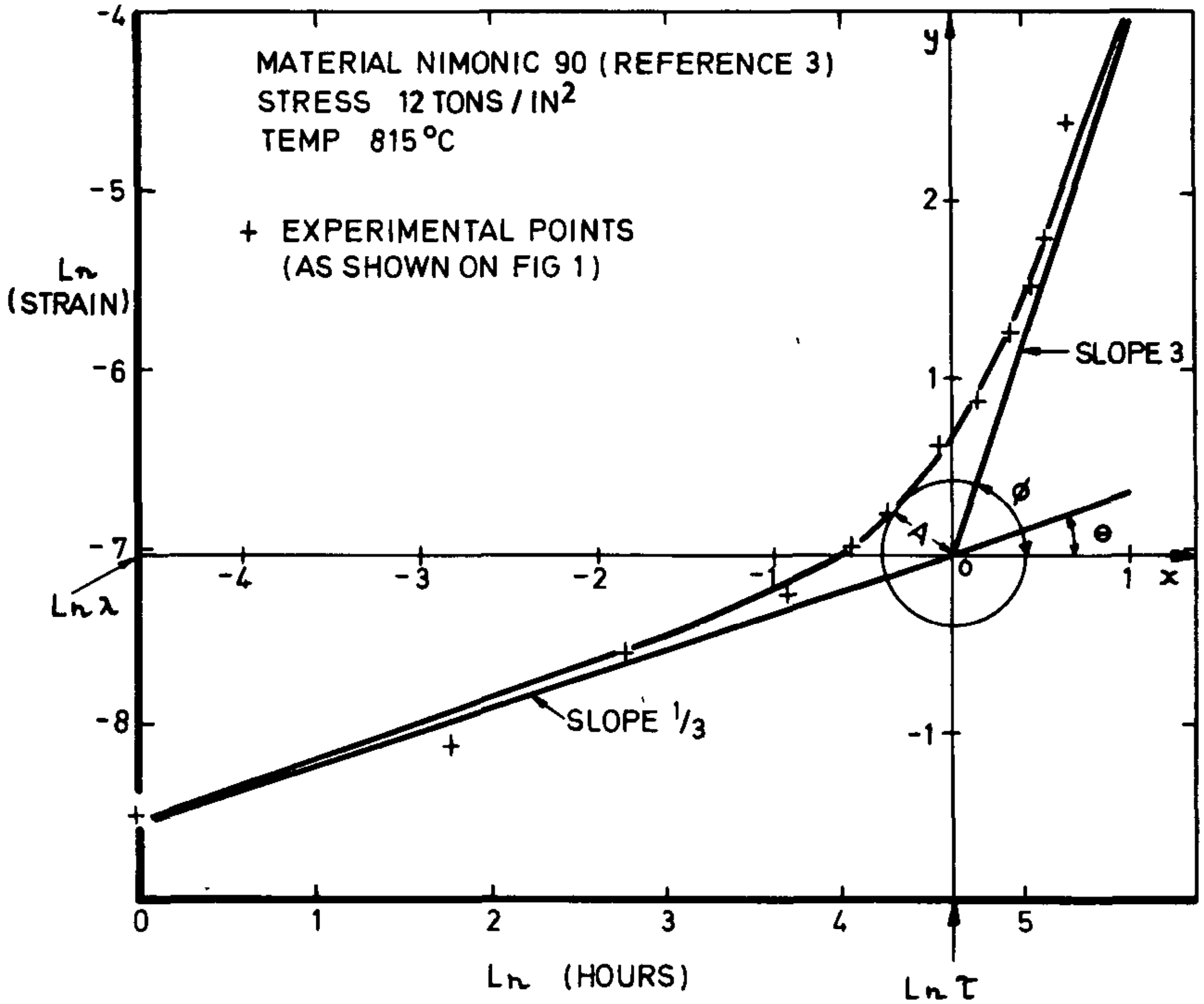

FIG. 2 TYPICAL LOGARITHMIC CREEP CURVE

FITTED WITH A HYPERBOLA

FIG. 3

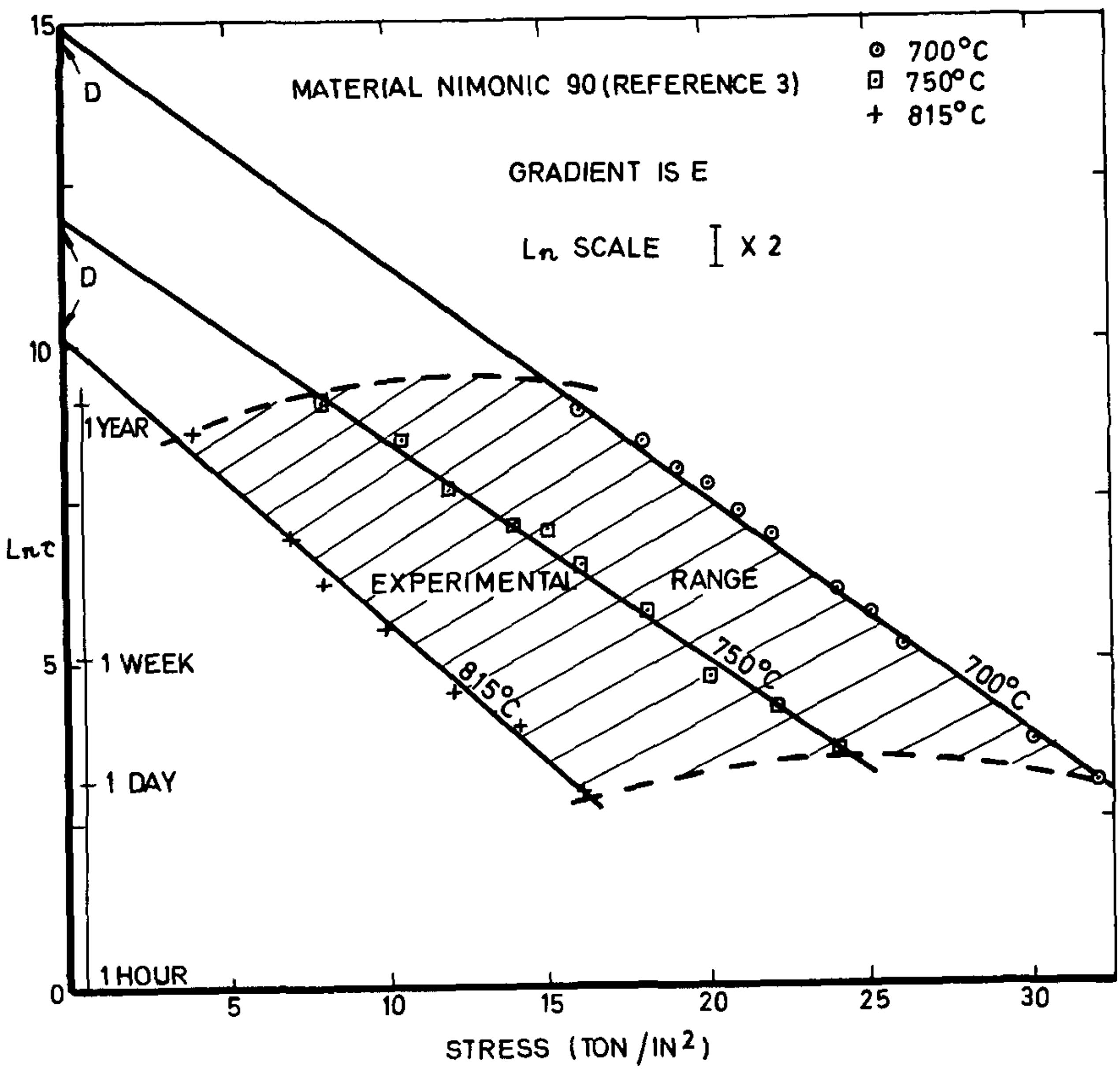

FIG. 3 STRESS AND TEMPERATURE VARIATION OF TIME SCALE

FIG. 4

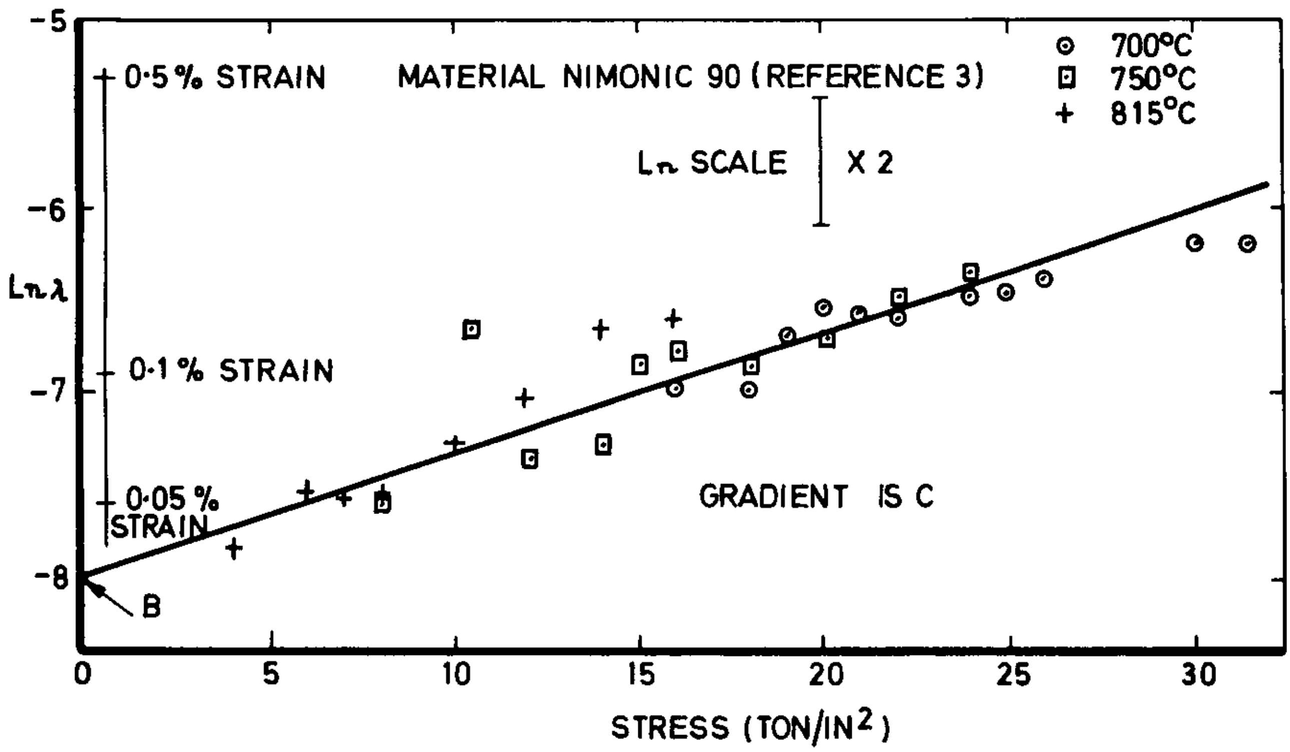

FIG. 4 STRESS AND TEMPERATURE VARIATION OF STRAIN SCALE

FIG. 5

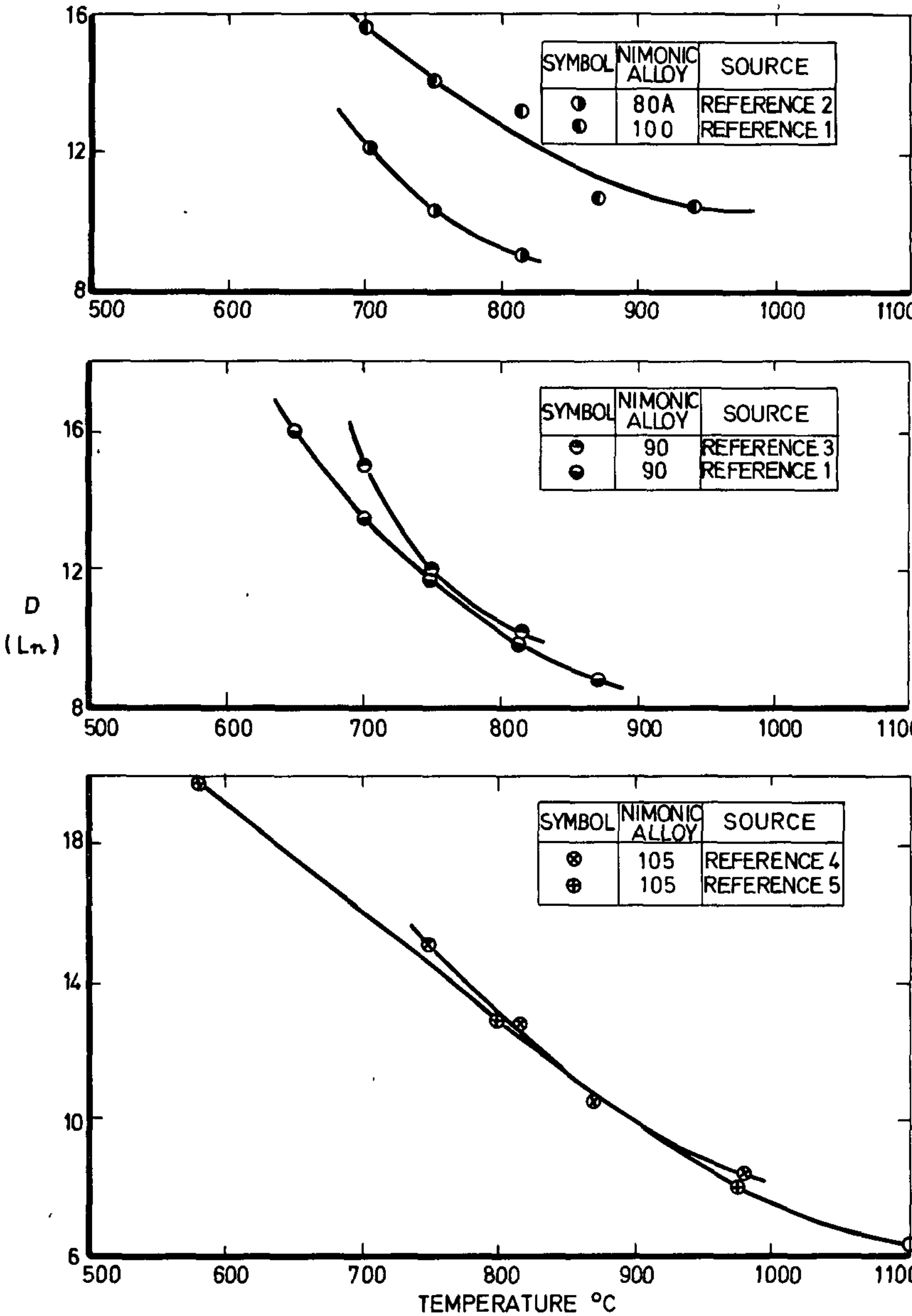

FIG. 5 TEMPERATURE VARIATION OF TIME SCALE

ZERO STRESS INTERCEPT (D)

FIG. 6

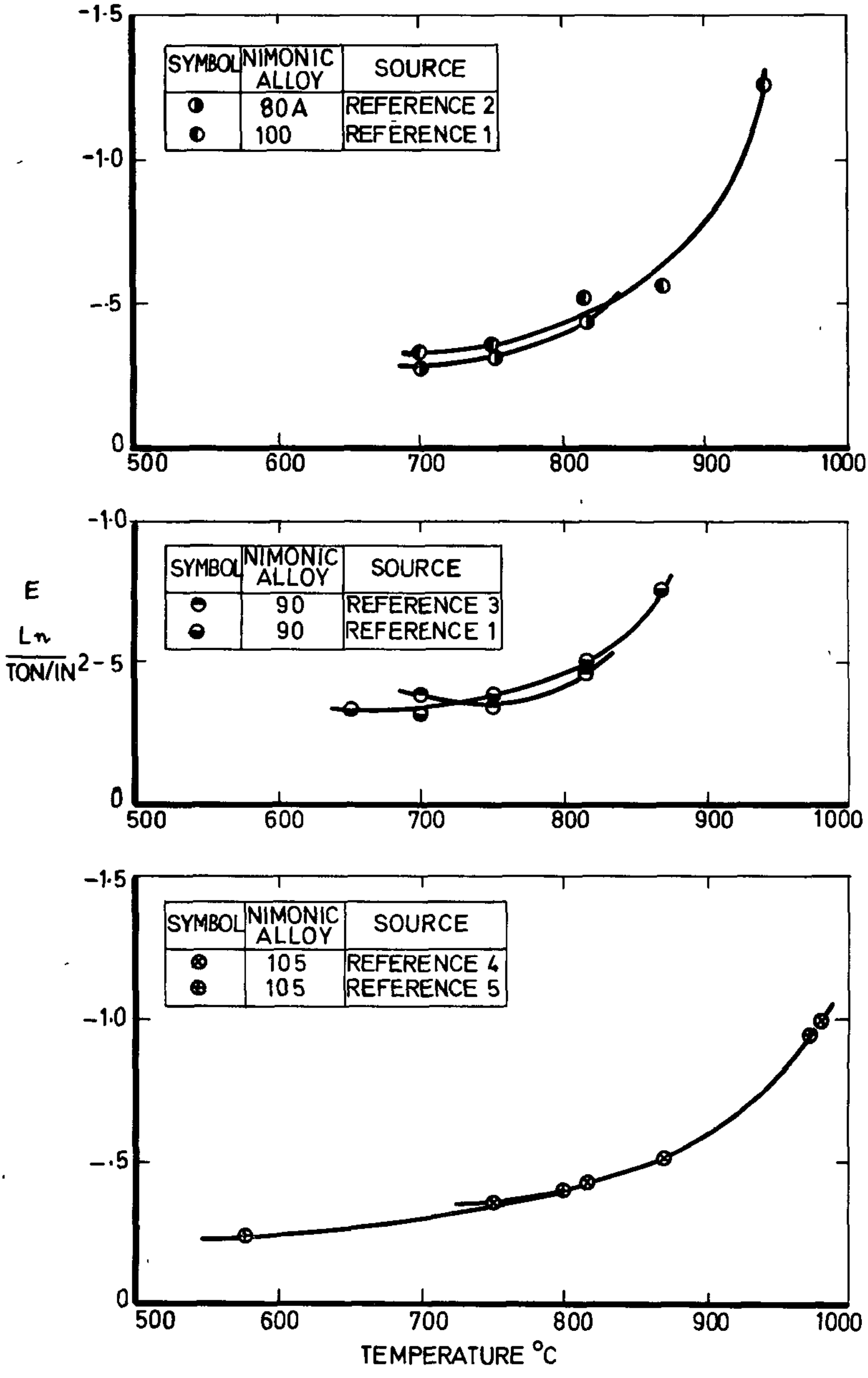

FIG.6 TEMPERATURE VARIATION OF TIME SCALE

STRESS DERIVATIVE (E)

FIG.7

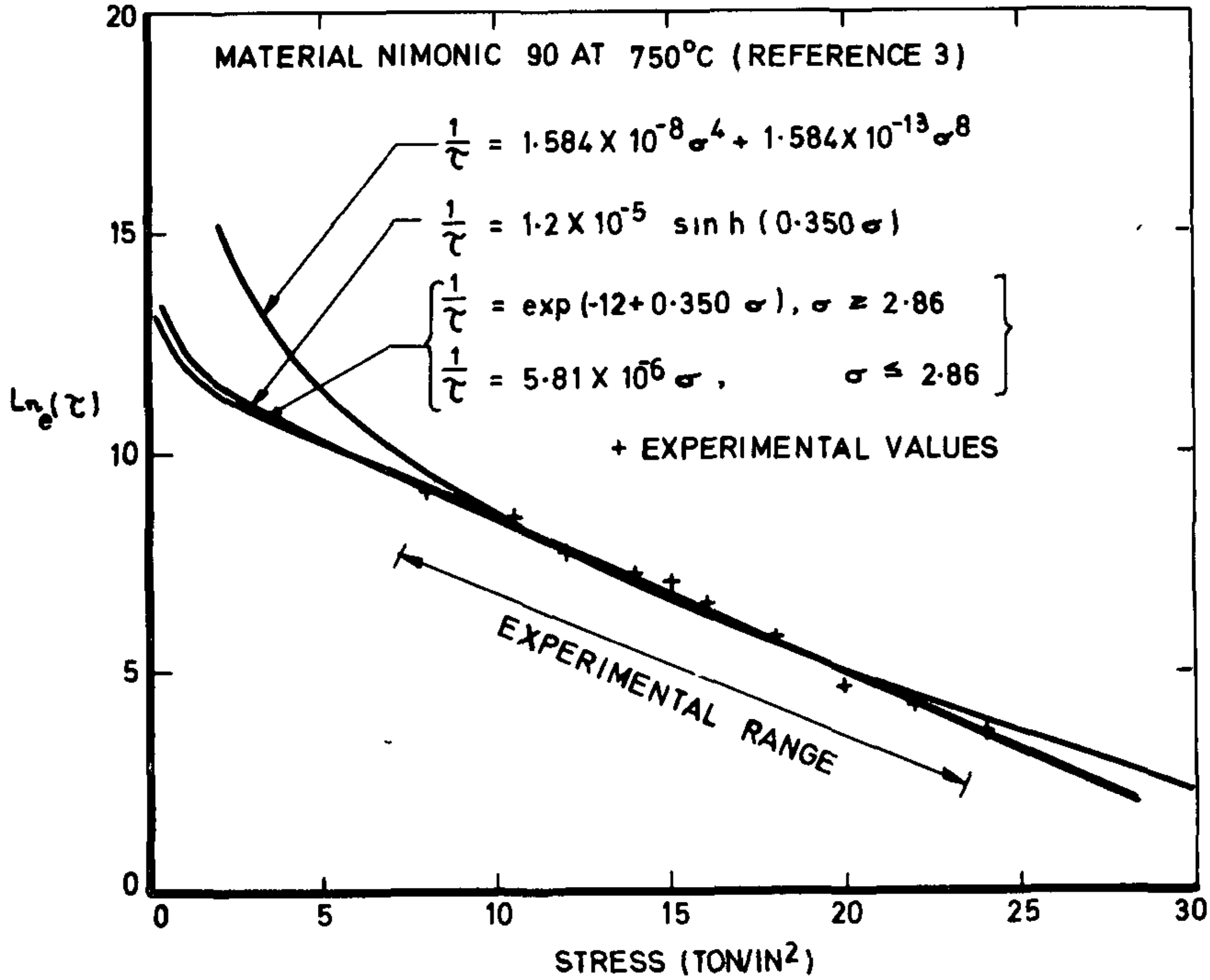

FIG. 7 STRESS DEPENDENCE FORMULAE

– A COMPARISON

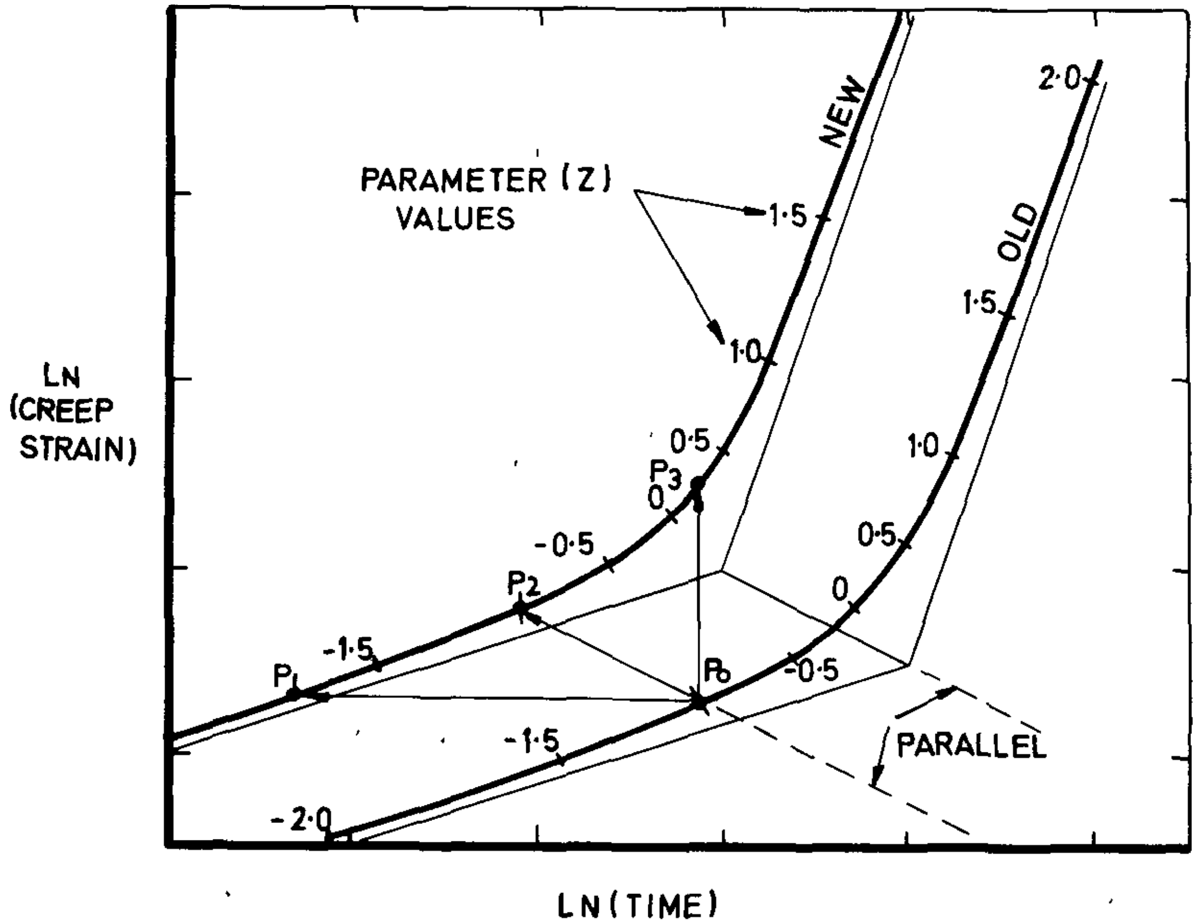

FIG. 8 STRAIN, PARAMETRIC AND TIME HARDENING

HYPOTHESES CONTRASTED

D 86675/1/129528 K4 5/67 CL

A.R.C. CP. No. 945 539.434:539.319
September 1966
Clarke, J. M.

A CONVENIENT REPRESENTATION OF CREEP STRAIN DATA FOR PROBLEMS INVOLVING TIME-VARYING STRESSES AND TEMPERATURES

An empirical approach to the representation of observed creep strain behaviour for a wide range of times, stresses and temperatures is outlined. The formulae are unusual in permitting the representation of primary and tertiary creep behaviour without forfeiting the convenience of explicit expressions for the strain rate using either the strain or time hardening hypotheses. They are therefore particularly suited for use in stress redistribution calculations

A comparison is made between the usual expressions for stress dependence. A table lists the arbitrary constants chosen to fit the creep behaviour of the Nimonic alloys 80A, 90, 100 and 105.

A.R.C. CP. No. 945 539.434:539.319
September 1966
Clarke, J. M.

A CONVENIENT REPRESENTATION OF CREEP STRAIN DATA FOR PROBLEMS INVOLVING TIME-VARYING STRESSES AND TEMPERATURES

An empirical approach to the representation of observed creep strain behaviour for a wide range of times, stresses and temperatures is outlined. The formulae are unusual in permitting the representation of primary and tertiary creep behaviour without forfeiting the convenience of explicit expressions for the strain rate using either the strain or time hardening hypotheses. They are therefore particularly suited for use in stress redistribution calculations.

A comparison is made between the usual expressions for stress dependence. A table lists the arbitrary constants chosen to fit the creep behaviour of the Nimonic alloys 80A, 90, 100 and 105.

A.R.C. CP. No. 945 539.434:539.319
September 1966
Clarke, J. M.

A CONVENIENT REPRESENTATION OF CREEP STRAIN DATA FOR PROBLEMS INVOLVING TIME-VARYING STRESSES AND TEMPERATURES

An empirical approach to the representation of observed creep strain behaviour for a wide range of times, stresses and temperatures is outlined. The formulae are unusual in permitting the representation of primary and tertiary creep behaviour without forfeiting the convenience of explicit expressions for the strain rate using either the strain or time hardening hypotheses. They are therefore particularly suited for use in stress redistribution calculations.

A comparison is made between the usual expressions for stress dependence. A table lists the arbitrary constants chosen to fit the creep behaviour of the Nimonic alloys 80A, 90, 100 and 105.

DETACHABLE ABSTRACT CARDS

C.P. No. 945

Printed and published by
HER MAJESTY'S STATIONERY OFFICE

To be purchased from
49 High Holborn, London W.C.1
423 Oxford Street, London W.1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
Brazennose Street, Manchester 2
50 Fairfax Street, Bristol 1
35 Smallbrook, Ringway, Birmingham 5
7 - 11 Linenhall Street, Belfast 2
or through any bookseller

Printed in England

C.P. No. 945

S.O. Code No 23-9017-45