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A Comparison of some Methods for Predicting Creep Strain and Rupture under Cyclic Loading

By

J. M. Clarke

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A comparison of some methods for predicting creep strain and rupture under cyclic loading

- by -

J. M. Clarke

SUMMARY

There are many good reasons for attempting to predict creep behaviour under conditions of varying stress and temperature from data derived from tests performed at constant stress and temperature. This Report starts by describing the most straightforward hypotheses at present used for this purpose.

Computed results for cyclic variations have shown that

(i) the "strain hardening" and "life fraction" hypotheses predict very similar rupture times

(ii) the times to a given creep strain do not depend on the frequency of the cycles or the sequence of loading within the cycles providing there are several (10 or more) cycles involved

(iii) when a substantial proportion (more than about two-thirds) of the creep life shows a "tertiary" behaviour the "time hardening" hypothesis predicts the shortest rupture times for the same cyclic loading.

A method is demonstrated for evaluating effective mean stresses or temperatures for any cyclic conditions according to either strain or time hardening hypotheses.

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* Replaces N.G.T.E. R 288 (A.R.C.29 498)

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2	Derivation of temperature and stress sensitivities from minimum strain rate data
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1.0 Introduction

This Report examines and contrasts the more straightforward methods for estimating creep strains and rupture times under conditions of varying stress and temperature, using data derived from tests at constant stress and temperature. The comparison, although purely theoretical, serves to emphasise some inherent features of each hypothesis and will simplify interpretation and design of subsequent experimental work.

The most sweeping assumption is that it is possible to deduce variable loading behaviour from constant loading behaviour. Although constant stress/temperature test results can be described by an expression for creep strain rate, using a single parameter (e.g., strain or time) to represent the effects of previous loading history, it does not follow that the same parameter suffices for describing the influence of previous loading during variable loading tests. However a vast amount of constant load data exists and it is natural and necessary to attempt first to use this information and assess its relevance to variable loading. Because much more data exist for simple rupture tests than for tests during which strain is measured it is particularly important to compare results derived from rupture data with those obtainable by application of various "hardening hypotheses" and strain data.

2.0 Strain accumulation hypotheses

Because stress, temperature and time are the independent variables and creep strain is the measured variable it is customary to present the results of creep strain tests by fitting empirical formulae of the general form:

$$\text{strain} = F_1 \text{ (stress, temperature, time)} \qquad \ldots .(1)$$

where F_1 stands for an undefined function of the bracketed variables, and time is measured from the application of the load.

These formulae can be differentiated to give incremental relations of the form:

$$\text{strain rate} = F_2 \text{ (stress, temperature, time)} \qquad \ldots .(2)$$

More generally the loading history can be represented by any parameter which varies during the test so that

$$\text{strain rate} = F_3 \text{ (stress, temperature, parameter)} \qquad \ldots .(3)$$

The use of some parameter other than time in the strain rate expression has the advantage that it avoids doubts about the time scale origin, which can be obscure for certain loading histories.

A possible choice for the parameter is accumulated strain, so that:

$$\text{strain rate} = F_4(\text{stress, temperature, strain}) \qquad \ldots.(4)$$

Finally it may be possible to separate the loading from the history by choosing a parameter (z) such that

$$\text{strain rate} = F_5(\text{stress, temperature}) \cdot F_6(z) \qquad \ldots.(5)$$

The existence of an expression having the form of Equation (5) is implied by the constant shape of the ln (strain) versus ln (time) results for a wide range of stresses and temperatures. In the analysis described in Reference 1 the chosen shape is hyperbolic and the parameter can conveniently be the one used for the parametric representation of a hyperbola.

In this Report, when discussing conditions of varying stress and temperature, applications of Equations (2), (4) and (5) are referred to as "time hardening", "strain hardening", and "parameter hardening" respectively. Their application involves the assumption that the third independent variable, which represents loading history, remains unchanged when the stress or temperature is changed quickly. The expressions for accumulated strain in each case are:

$$\varepsilon = \int_0^t F_2(\sigma, T, t)\, dt \qquad \text{(time hardening)} \qquad \ldots.(6)$$

$$\varepsilon = \int_0^t F_3(\sigma, T, \varepsilon)\, dt \qquad \text{(strain hardening)} \qquad \ldots.(7)$$

$$\varepsilon = \int_0^t F_5(\sigma, T) \cdot F_6(z)\, dt \qquad \text{(parameter hardening)} \qquad \ldots.(8)$$

For time varying stress or temperature these expressions generally give different answers. However to a first approximation the results of creep tests at constant stress and temperature (including primary and tertiary strain regions) can be described by an expression in the form of Equation (5) where the parameter is creep strain. This follows from the fact that the predominant influence of stress and temperature on creep tests is to change the time scale. If this were the only influence strain would serve perfectly as the parameter in Equation (5). The application of a parametric hardening hypothesis therefore gives results close to those of strain hardening, particularly if the range of stresses and temperatures is small. For this reason the parametric hardening hypothesis is not treated separately in the following Sections.

3.0 Rupture time hypotheses

3.1 Life fraction

This hypothesis is the easiest to apply because it requires no information regarding strain. Given data from constant stress and temperature tests in the form

$$\text{Rupture time} = t_R = F_7(\sigma, T) \qquad \text{....(9)}$$

then it is suggested that the rupture time under varying conditions can be deduced by finding t_R in the expression

$$\int_0^{t_R} \frac{dt}{F_7(\sigma, T)} = 1 \qquad \text{....(10)}$$

3.2 Hypotheses based on rupture strain

These hypotheses, in addition to strain rate information, require some information about rupture strains. It is assumed that given rupture strains in the form

$$\varepsilon_R = F_8(\sigma, T) \qquad \text{....(11)}$$

a rupture time can be deduced from the expression

$$t_R = \int_0^{\varepsilon_R} \frac{d\varepsilon}{\dot{\varepsilon}} \qquad \text{....(12)}$$

Naturally for each strain rate expression ((2), (3) or (5)), Equation (12) will generally yield a different rupture time.

4.0 Computer program

In order to investigate the range of difference involved for cyclic stresses and temperatures a computer program (in Elliott 803 ALGOL 60) has been written. It can accept up to six step changes of stress and temperature per cycle with any proportion of the cycle period at each condition. Some selected results of applying this program are presented in the next Section. The program is available for the use of others and can readily be applied to more specific problems or adapted to compare more complex hypotheses.

Use is made in the program of formulae for creep strain which assume that the plot of ln (creep strain) against ln (time) may be represented by a hyperbola[1]. In the case of primary and tertiary exponents of $\frac{1}{3}$ and 3 respectively the hyperbola is

$$3 \ln^2 \left(\frac{\varepsilon}{\lambda}\right) + 3 \ln^2 \left(\frac{t}{\tau}\right) - 10 \ln \left(\frac{\varepsilon}{\lambda}\right) \ln \left(\frac{t}{\tau}\right) = 8A^2$$

Different numerical coefficients may be used for other exponents. Variations with stress and temperature are expressed by changing the strain scale factor (λ) and the time scale factor (τ) according to the formulae

$$\ln \lambda = B + C \cdot \sigma$$

and

$$\ln \tau = D + E \cdot \sigma$$

Although A, B and C are taken as constants, D and E are tabulated functions of temperature.

For simplicity the program takes 15 per cent to be a typical creep rupture strain. This assumption is not particularly critical - a 50 per cent reduction in rupture strain would correspond to about a 20 per cent reduction in rupture time. As will be seen in the next Section this uncertainty is much less than that involved in other assumptions.

5.0 Results

Figure 1 shows a loading cycle and the corresponding calculated strain accumulation according to the time and strain hardening hypotheses. The most obvious results are

(i) that time hardening implies a much shorter rupture time

(ii) that for strains approaching rupture the average accumulation follows the same time law (t^m) as that observed for steady loading.

Other calculations using different cycles show that providing there are many cycles neither the sequence of loadings within the cycles nor the frequency of the cycles influence the rupture times. These results, summarised in Table I, are a direct consequence of the assumption that an instantaneous load or temperature change does not do any damage.

The calculations also include an estimate of rupture time based on the life fraction theory using a constant fracture strain. The results confirm the observation by Berkovits[2] that strain hardening and life fraction hypotheses give the same rupture times providing

(a) a constant rupture strain can be assumed

(b) changes of stress and temperature only effect the time scale of the creep processes.

It is worth adding that creep strain need not be the parameter having a critical value at rupture. If any parameter, say y, has a critical value at rupture and if an equation of the form

$$dy = F_9(\sigma,T) \cdot F_{10}(y) \cdot dt \qquad \text{....(13)}$$

connects t and y then the life fraction theory holds. The analysis in the next Section explains the difference between strain and time hardening results and serves to make the difference more general.

6.0 Explanation of results for cyclic loading

It is assumed that the strain increments are occurring at a general level of strain such that strain (ε) and time (t) can be related by the approximate expression

$$\varepsilon = A(\sigma,T)\, t^m \qquad \text{....(14)}$$

for constant σ and T.

The corresponding strain rates are

$$\dot{\varepsilon}_T = m\, A\, t^{m-1} \qquad \text{....(15)}$$

for time hardening, and

$$\dot{\varepsilon}_S = m\, A^{\frac{1}{m}}\, \varepsilon^{\frac{m-1}{m}} \qquad \ldots.(16)$$

for strain hardening.

For a cycle starting at t_1 and ending at t_2 the appropriate mean strain rates are

$$\left(\frac{\varepsilon_2 - \varepsilon_1}{t_2 - t_1}\right)_T = \frac{\int_{t_1}^{t_2} m\, A\, t^{m-1}\, dt}{t_2 - t_1} \qquad \ldots.(17)$$

for time hardening

$$\left(\frac{\varepsilon_2 - \varepsilon_1}{t_2 - t_1}\right)_S = \frac{\int_{t_1}^{t_2} m\, A^{\frac{1}{m}}\, \varepsilon^{\frac{m-1}{m}}\, dt}{t_2 - t_1} \qquad \ldots.(18)$$

for strain hardening. Now when the variations of t and ε within the interval are much smaller than the initial values these reduce to

$$\left(\frac{\varepsilon_2 - \varepsilon_1}{t_2 - t_1}\right)_T \approx m \cdot \frac{\int_{t_1}^{t_2} A\, dt}{t_2 - t_1} \cdot t_1^{\,m-1} \qquad \ldots.(19)$$

and

$$\left(\frac{\varepsilon_2 - \varepsilon_1}{t_2 - t_1}\right)_S \approx m \cdot \frac{\int_{t_1}^{t_2} A^{\frac{1}{m}}\, dt}{t_2 - t_1} \cdot \varepsilon_1^{\frac{m-1}{m}} \qquad \text{....(20)}$$

Comparison with Equations (15) and (16) shows that the effective mean value of the coefficient A in Equation (14) for cyclic loading is given by

$$A_T = \frac{\int_{t_1}^{t_2} A\, dt}{t_2 - t_1} \qquad \text{....(21)}$$

for time hardening and

$$A_S = \left(\frac{\int_{t_1}^{t_2} A^{\frac{1}{m}}\, dt}{t_2 - t_1}\right)^m \qquad \text{....(22)}$$

for strain hardening. It is not immediately clear that $A_S < A_T$ as implied by the computed results but the following theorem from the theory of inequalities[3] serves to show that this is always the case for $m > 1$.

<u>Theorem</u> If $\alpha, \beta, \ldots, \lambda$ are positive and $\alpha + \beta + \ldots + \lambda = 1$, then

$$\int f^{\alpha} g^{\beta} \ldots l^{\lambda}\, dx < \left(\int f\, dx\right)^{\alpha} \left(\int g\, dx\right)^{\beta} \ldots \left(\int l\, dx\right)^{\lambda}$$

where f, g .... l are arbitrary positive functions of x and the integration extends over positive values of x, unless one of the functions is null or all are effectively proportional.

Taking the particular case

$$\alpha = \beta = \dots = \lambda = \frac{1}{m}$$

and

$$g = \dots = l = 1$$

then the theorem reduces to

$$\int f^{\frac{1}{m}}\,dx < \left(\int f\,dx\right)^{\frac{1}{m}} \left(\int dx\right)^{\frac{m-1}{m}}$$

i.e.,

$$\left(\frac{\int f^{\frac{1}{m}}\,dx}{\int dx}\right)^{m} < \left(\frac{\int f\,dx}{\int dx}\right)$$

which shows that for arbitrary variations of $A(\sigma,T)$ in the time interval and for positive integral values of m greater than unity

$$A_S < A_T$$

Thus for tertiary creep, with a time exponent m equal to 3, time hardening predicts faster strain rates. On the other hand the same analysis serves to show that for high frequency cyclic loading during primary creep the time hardening would predict the slower rate because in that case $m < 1$ and the inequality sign is reversed. When the material shows an accelerating creep rate for a major portion (say about two-thirds) of its creep life then the predominant effects on rupture time for cyclic conditions correspond to values of m greater than unity.

It has therefore been demonstrated that under cyclic conditions strain and time hardening theories will give different answers for the mean strain rates. This extends the results of Reference 4 which compare the strain rates under monotonically changing conditions. All these results are summarised in the table at the end of the Conclusions in Section 8.0.

7.0 The evaluation of effective mean stresses and temperatures for cyclic loading

The results shown on Figure 1 indicate that the cyclic strain result for this cycle using the strain hardening hypothesis corresponds roughly to a constant load condition of 9·7 ton/in^2 and 838°C. This Section shows how such effective mean conditions can be estimated from creep strain or rupture data. A first requirement is to choose an expression for the stress and temperature dependence. The following are some simple possibilities:

$$\dot{\varepsilon}_{min} = \dot{\varepsilon}_0\Big(1 + p(\sigma - \sigma_0)\Big)\Big(1 + q(T - T_0)\Big) \qquad \text{....(23)}$$

$$\dot{\varepsilon}_{min} = \dot{\varepsilon}_0\left(\frac{\sigma}{\sigma_0}\right)^{p\sigma_0}\left(\frac{T}{T_0}\right)^{qT_0} \qquad \text{....(24)}$$

$$\dot{\varepsilon}_{min} = \dot{\varepsilon}_0 \exp\Big(p(\sigma - \sigma_0) + q(T - T_0)\Big) \qquad \text{....(25)}$$

where $\dot{\varepsilon}_{min}$ is the minimum (i.e., secondary) strain rate at stress σ and temperature T. It can be seen that the three formulae are centred on the stress σ_0 and temperature T_0, i.e., at these conditions and for small excursions from these conditions they agree. In each case

$$\dot{\varepsilon}_{min} = \dot{\varepsilon}_0(1 + p \cdot \delta\sigma + q \cdot \delta T) \qquad \text{....(26)}$$

Their relative accuracy for larger excursions is compared on Figure 2 in which the straight lines correspond to the exponential expression and the others are shown as broken curved lines.

Because the exponential expression evidently leads to more accurate extrapolation it is used below. Figure 3 shows the corresponding presentation based on rupture times. The values for stress sensitivity (p) and temperature sensitivity (q) can be seen to be similar as derived from minimum strain rates or rupture times.

Derived from	Stress sensitivity $p(\text{ton/in}^2)^{-1}$	Temp. sensitivity $q(^\circ C)^{-1}$
Minimum creep rates	0·541	0·056
Rupture times	0·554	0·049

(Nimonic 90 at 10 ton/in^2 825°C)

In both cases the sensitivities are at constant strain because minimum strain rates and rupture times both occur at roughly uniform strain levels. It therefore follows from comparison of Equation (25) with Equation (16) that

$$A_0^{\frac{1}{m}} \exp\left(p(\sigma - \sigma_0) + q(T - T_0)\right) = A^{\frac{1}{m}} \qquad \text{....(27)}$$

and introducing Equation (22) we have

$$A_S^{\frac{1}{m}} = A_0^{\frac{1}{m}} \frac{\int_{t_1}^{t_2} \exp\left(p(\sigma - \sigma_0) + q(T - T_0)\right) dt}{t_2 - t_1} \qquad \text{....(28)}$$

The approximate expression for strain under cyclic loading conditions according to the strain hardening hypothesis is obtained by substituting A_S into Equation (14) which gives

$$\varepsilon = \left(\frac{\int_{t_1}^{t_2} \exp\left(p(\sigma - \sigma_0) + q(T - T_0)\right) dt}{t_2 - t_1}\right)^m A_0 \cdot t^m \qquad \text{....(29)}$$

while the corresponding expression for the time hardening hypothesis is

$$\varepsilon = \frac{\int_{t_1}^{t_2} \exp\Big(mp(\sigma - \sigma_0) + mq(T - T_0)\Big)\, dt}{t_2 - t_1} \cdot A_0 \cdot t^m \qquad \ldots.(30)$$

Equation (29) leads directly to the following definition for mean effective stress σ_{me} and temperature T_{me}, for the strain hardening hypothesis.

$$\exp\Big(p(\sigma_{me} - \sigma_0) + q(T_{me} - T_0)\Big) = \frac{\int_{t_1}^{t_2} \exp\Big(p(\sigma - \sigma_0) + q(T - T_0)\Big)\, dt}{t_2 - t_1} \qquad \ldots.(31)$$

For the time hardening hypothesis

$$\exp\Big(p(\sigma_{me} - \sigma_0) + q(T_{me} - T_0)\Big) = \left(\frac{\int_{t_1}^{t_2} \exp\Big(mp(\sigma - \sigma_0) + mq(T - T_0)\Big)\, dt}{t_2 - t_1}\right)^{\frac{1}{m}} \qquad \ldots.(32)$$

These definitions determine only the effective value of the combination

$$p\sigma_{me} + qT_{me}$$

The particular choice of values for σ_{me} and T_{me} is not important but it would seem natural to take the actual stress or temperature if one was constant and otherwise to take a simple time mean for one and to deduce the other from Equation (31) or Equation (32)

Example

For the cycle illustrated on Figure 1, and the stress and temperature sensitivities derived from Figure 2, Equation (31) becomes

$$\exp\left(0{\cdot}54(\sigma_{me} - 10) + 0{\cdot}056(T_{me} - 825)\right)$$

$$= \frac{\exp\,(0{\cdot}54\times1 + 0{\cdot}056\times5) + 2\times\exp\,(0{\cdot}056\times5) + 3\times\exp\,(0{\cdot}54\times-1 + 0{\cdot}056\times-15)}{6}$$

Hence $$0{\cdot}54(\sigma_{me} - 10) + 0{\cdot}056(T_{me} - 825) = 0{\cdot}546$$

Taking $$\sigma_{me} = \text{time mean stress}$$

$$= 9{\cdot}67 \text{ ton/in}^2$$

then $$T_{me} = 838^{\circ}\text{C}.$$

The strain results for these conditions can be seen from Figure 1 to give a good guide to the cyclic behaviour as computed by a much more involved procedure.

8.0 Conclusions

A computer program and creep strain data (derived from tests at constant stress and temperature) have been used to calculate on the basis of "time hardening", "strain hardening" and "life fraction" hypotheses the times to reach a strain level typical for rupture. A simple analytical treatment has explained the results and permitted them to be considered general.

The results have shown that

(i) The "strain hardening" and "life fraction" theories predict very similar rupture times.

(ii) The times to a given strain do not depend on the frequency of the cycles or the sequence of loading within each cycle, providing there are several (10 or more) cycles involved.

(iii) When a substantial proportion (more than about two-thirds) of the creep life shows a "tertiary" behaviour the time hardening theory predicts the shorter rupture times for the same cyclic loading.

A method has been demonstrated for using creep or rupture data to derive stress and temperature sensitivities from which cyclic loading conditions can be integrated to obtain effective mean stresses and temperatures for strain and time hardening hypotheses.

The comparison between strain and time hardening theories under monotonically changing loads[4], and the present results can be summarised by the following table comparing mean strain rates.

	Decelerating (primary) creep ($m < 1$)	Accelerating (tertiary) creep ($m > 1$)
Increasing stress and/or temperature	$\dot{\varepsilon}_S > \dot{\varepsilon}_T$	$\dot{\varepsilon}_S < \dot{\varepsilon}_T$
Decreasing stress and/or temperature	$\dot{\varepsilon}_S < \dot{\varepsilon}_T$	$\dot{\varepsilon}_S > \dot{\varepsilon}_T$
Cyclic stress and/or temperature	$\dot{\varepsilon}_S > \dot{\varepsilon}_T$*	$\dot{\varepsilon}_S < \dot{\varepsilon}_T$

*The cycle period must be much less than the duration of primary creep

REFERENCES

No.	Author(s)	Title, etc.
1	J. M. Clarke	A convenient representation of creep strain data for problems involving time-varying stresses and temperatures. A.R.C. Current Paper No. 945, September, 1966
2	A. Berkovits	Investigation of the analytical hypotheses for determining material creep behaviour under varied loads with an application to 2024-T3 aluminium alloy sheet in tension at 400°F. N.A.S.A. TN D-799, May, 1961
3	H. L. Polya	Inequalities Cambridge University Press, 1959
4	J. M. Clarke	Conference on thermal loading and creep in structures and components. Discussion at Session 4. Proc. I. Mech. E. p.169, Vol. 178, Part 3L, 1963-4

TABLE I

Summary of rupture time results

Cycle details

A	As shown on Figure 1
B	One-tenth of period at 860°C followed by nine-tenths of period at 826°C, stress constant at 10 ton/in²
C	Nine-tenths of period at 826°C followed by one-tenth of period at 860°C, stress constant at 10 ton/in²

Calculated rupture times in hours

Cycle type	A	B			C	
Cycle period (hr)	20	50	10	2·5	50	10
Time hardening	140	152	151	150	148	150
Strain hardening	310	350	350	350	350	350
Life fraction	313	350	350	350	350	350

APPENDIX

Notation

A	function of stress and temperature
f, g, h l	arbitrary positive functions of the same variable (x)
F(....)	function of the bracketed variable
m	exponent of time in creep strain formulae
p	sensitivity of creep strain rate to stress change
q	sensitivity of creep strain rate to temperature change
t	time
T	temperature
x	independent variable
y,z	material parameters which change during a creep test
$\alpha, \beta, \ldots \lambda$	positive numbers adding up to 1
ε	creep strain
$\dot{\varepsilon}$	creep strain time derivative
σ	stress

Subscripts

o	a constant reference value
$_{1}$, $_{2}$	before and after a load cycle
$_{1}$, $_{2}$ .... $_{10}$	used to distinguish various F functions
me	mean effective
min	minimum
R	rupture
S	strain hardening hypothesis
T	time hardening hypothesis

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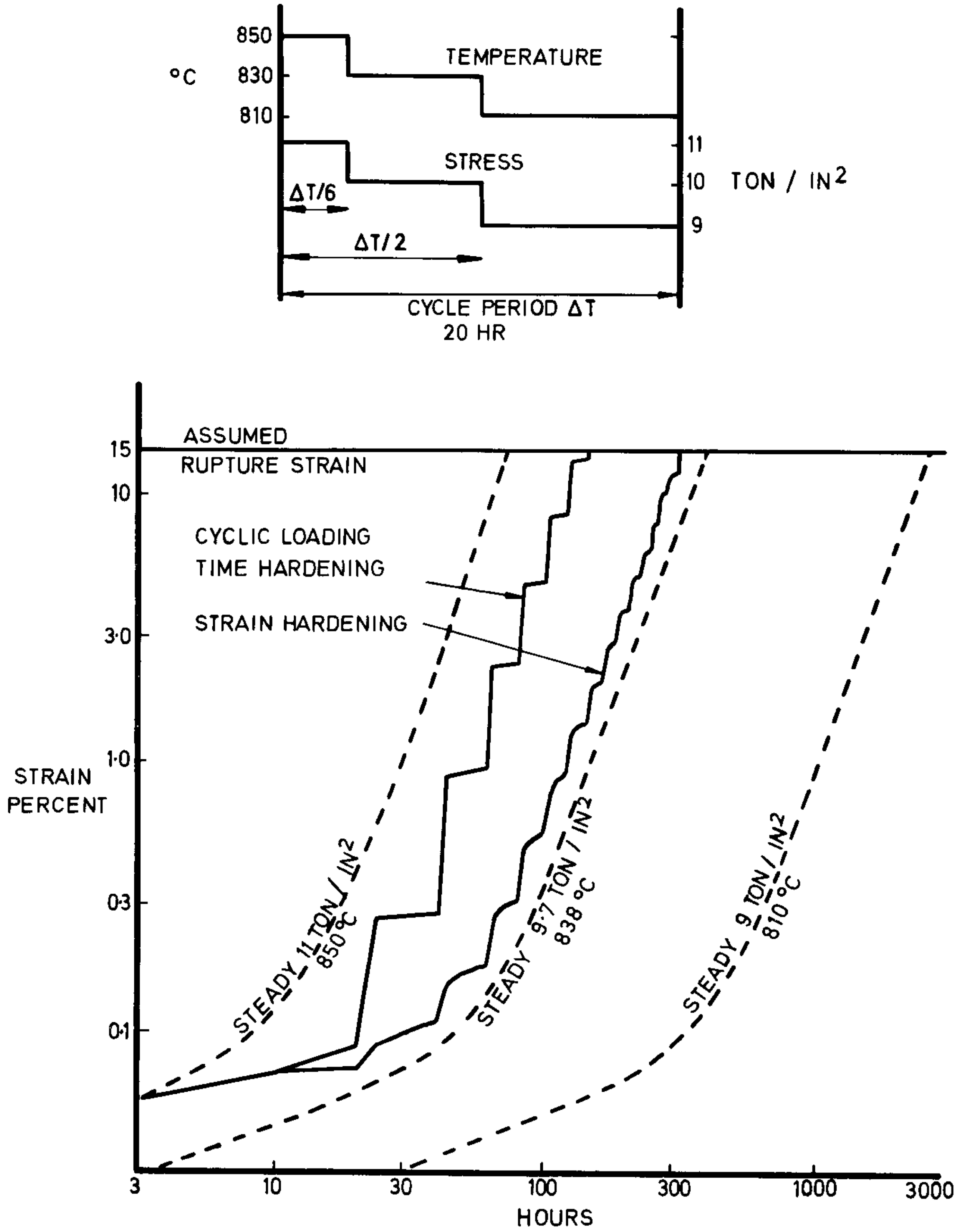

FIG. 1 RESULTS OF SOME CYCLIC LOADING CALCULATIONS

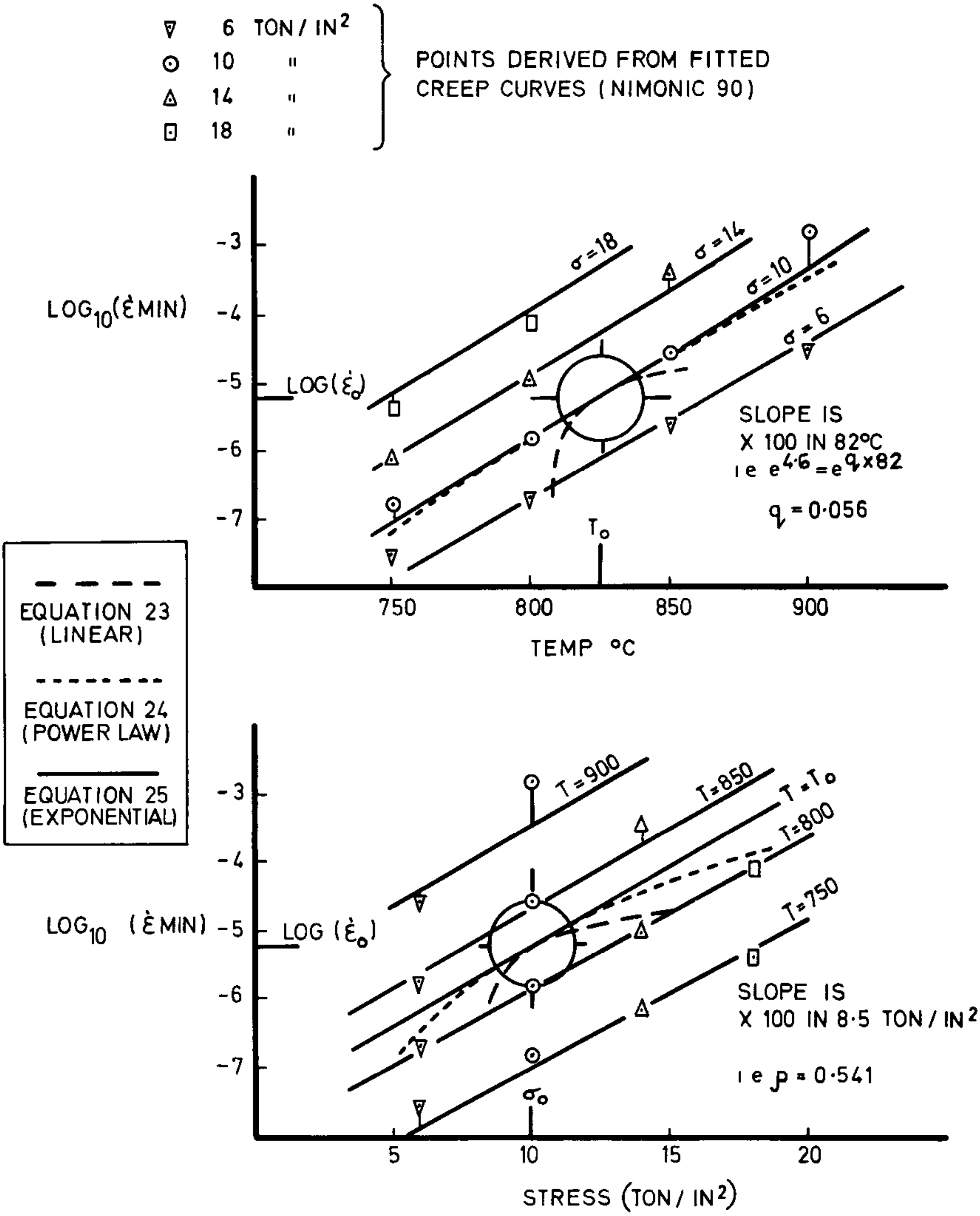

FIG. 2 DERIVATION OF TEMP AND STRESS SENSITIVITIES FROM MINIMUM STRAIN RATE DATA

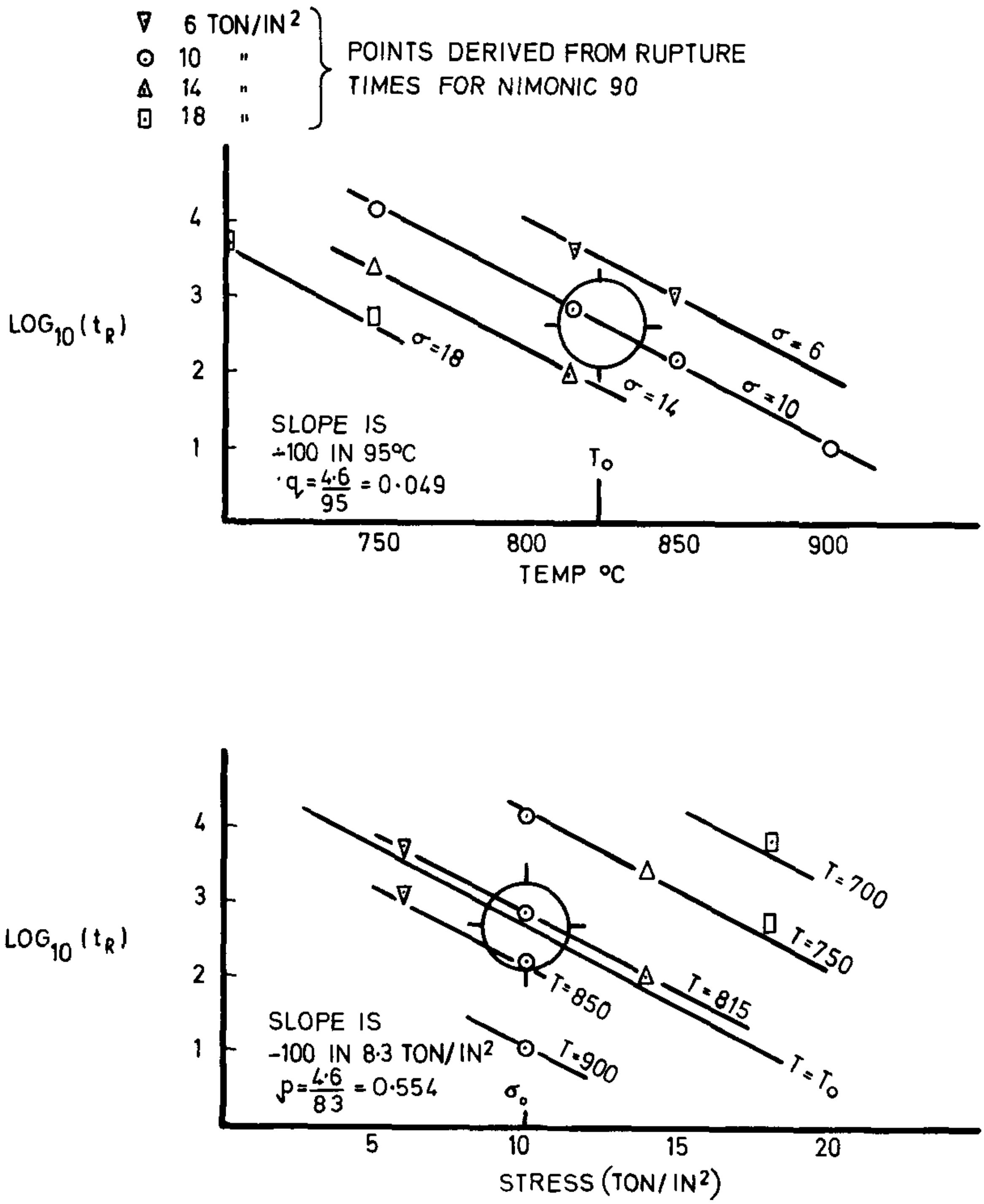

FIG.3 DERIVATION OF TEMP. AND STRESS SENSITIVITIES FROM RUPTURE TIME DATA

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