DAMAGE DESCRIPTION USING POWER TYPE RELATIONSHIP

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ABSTRACT

In the evaluation of creep test results, power type relationships of two parameters are widely used. In these relationships the material responses are characterised by two experimentally determined parameters. In this paper there is an evaluation of a great numbers of creep testing data of fcc, bcc and hcp materials. The parameters in each of these equations are not independent. They have a physically based correlation. The creep sensitivity will be defined on the basis of melting temperature.

KEYWORDS

Secondary creep rate, creep of FCC, BCC and HCP metals, empirical relationships, correlation among empirical parameters, thermodynamical background, creep sensitivity.

INTRODUCTION

During creep testing the specimens are loaded, and the responses resulting from self-organised damage processes are measured. Then a connection between the loading and the response parameters is sought. Two possibilities exist. One of them is an engineering approach, when the material response is characterised by experimentally determined constants. In this case the most simple relationship is the power type one having two parameters, i.e.

$$y=ax^n, \tag{1}$$

where **y** is the parameter related to material response, **x** is the loading parameter, **a** and **n** are the material characteristics. The other possibility in the self-organised damage process taking place in the material during testing is to apply physical, thermodinamical models. In both cases the material is regarded as a *"black box"* shown in Figure 1. only the levels are different in a description of damage process. The engineering approach characterised by relationship of (1) is very simple in use because, depending on the value of **n**, quite different behaviour can be expressed.

In technical creep the following empirical relationships are widely used:

$$\varepsilon = C_1\sigma^{n} \tag{2}$$

$$t_t = C'_1\sigma^{-n'_1} \tag{3}$$

$$\varepsilon = C''_1 t_t^{-n''_1} \tag{4}$$

where

- $\boldsymbol{\varepsilon}$ is the secondary creep rate,
- $\boldsymbol{\sigma}$ is the applied stress,
- $\mathbf{t_t}$ - is the life time (rupture time),
- $\mathbf{C_i}$ and $\mathbf{n_i}$ - are the material characteristics (i=1,2,3).

The equation (2) is called the *NORTON* relationship, proposed by him in 1929.

External parameters

- σ,
- Temperature
- Environment

Macroscopic parameters

- Creep: t_t, ε

Microscopic parameters

$$t_t = t_0 \cdot \exp \cdot \left[U(\sigma) \big/ kT \right]$$

- U_0, t_0, σ_0
- U_0, t_0, γ

Fig 1. The **"black box"** approach of material

What is the similarity between equations (2)-(4)? They express the damage processes taking place in materials in the range from zero up to unity (up to fracture) during testing. That means that a selected damage phenomenon is characterised by two parameters. The questions that arise are the following:

- Why does a given damage phenomena need to be characterised by two parameters?
- If the damage processes are similar in different materials are the parameters $\mathbf{C_i}$ and $\mathbf{n_i}$ independent or not?

The aim of this paper is to discuss these questions.

CORRELATION AMONG EMPIRICAL PARAMETERS

In order to illustrate a possible correlation, Figure 2 shows the correlation of $\boldsymbol{lgC_1}$ and $\boldsymbol{n_1}$ for **Mo-alloys** tested in the range of 1500-2000 ^oC. It can be seen that quite a good correlation exists between two empirically determined material constants. In Figure 3 a great number of results of experimental creep data are summarised for pure FCC metals; in Figure 4 for the BCC metals, in Figure 5 for HCP metals and in Figure 6 for steels and alloys.

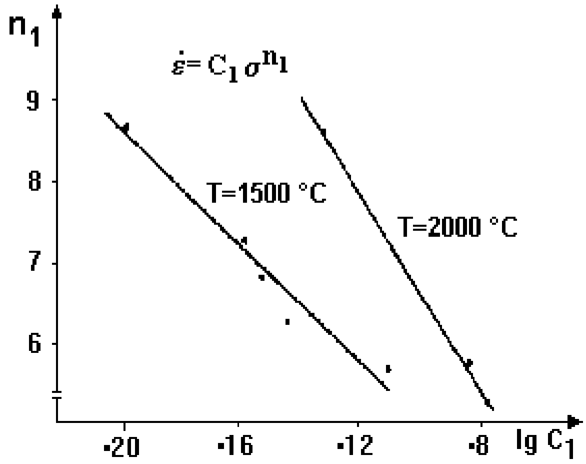

Fig. 2. The correlation between **lgC$_1$** and **n$_1$** for **Mo-alloy** tested at 1500 and 2000 °C
[stress in **MPa**, creep rate in **sec^{-1}**]

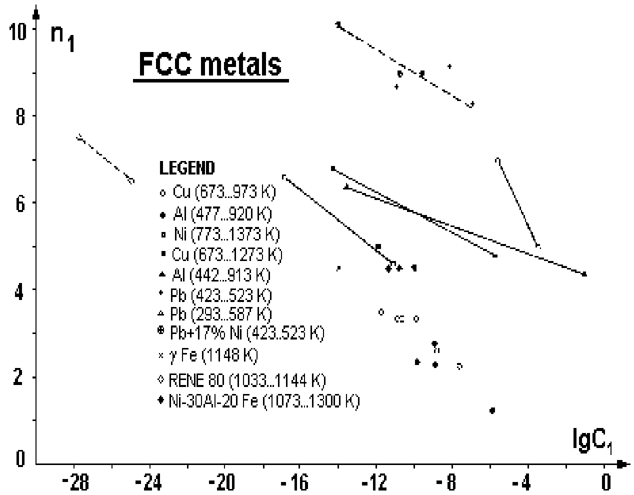

Fig 3. Correlation between n_1 and lgC_1 parameters for steady creep rate of **FCC-**metals
[stress in **MPa**, creep rate in **sec^{-1}**]

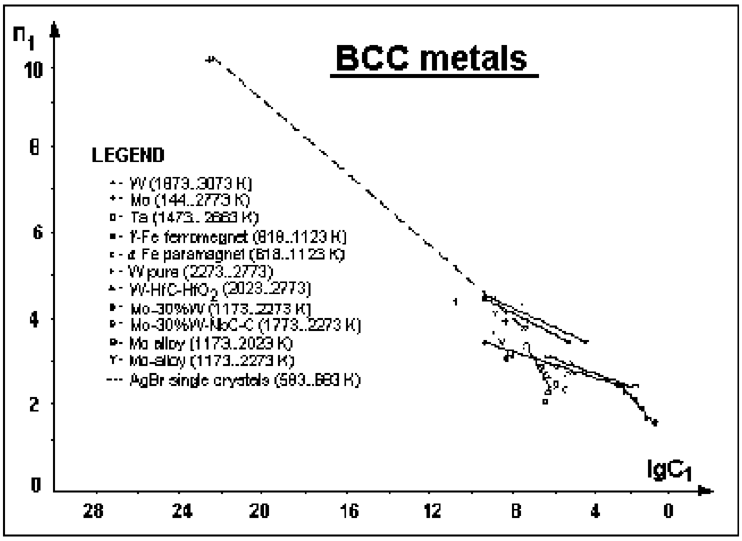

Fig. 4. Correlation between n_1 and lgC_1 parameters for steady creep rate of **BCC-**metals
[stress in **MPa**, creep rate in **sec^{-1}**]

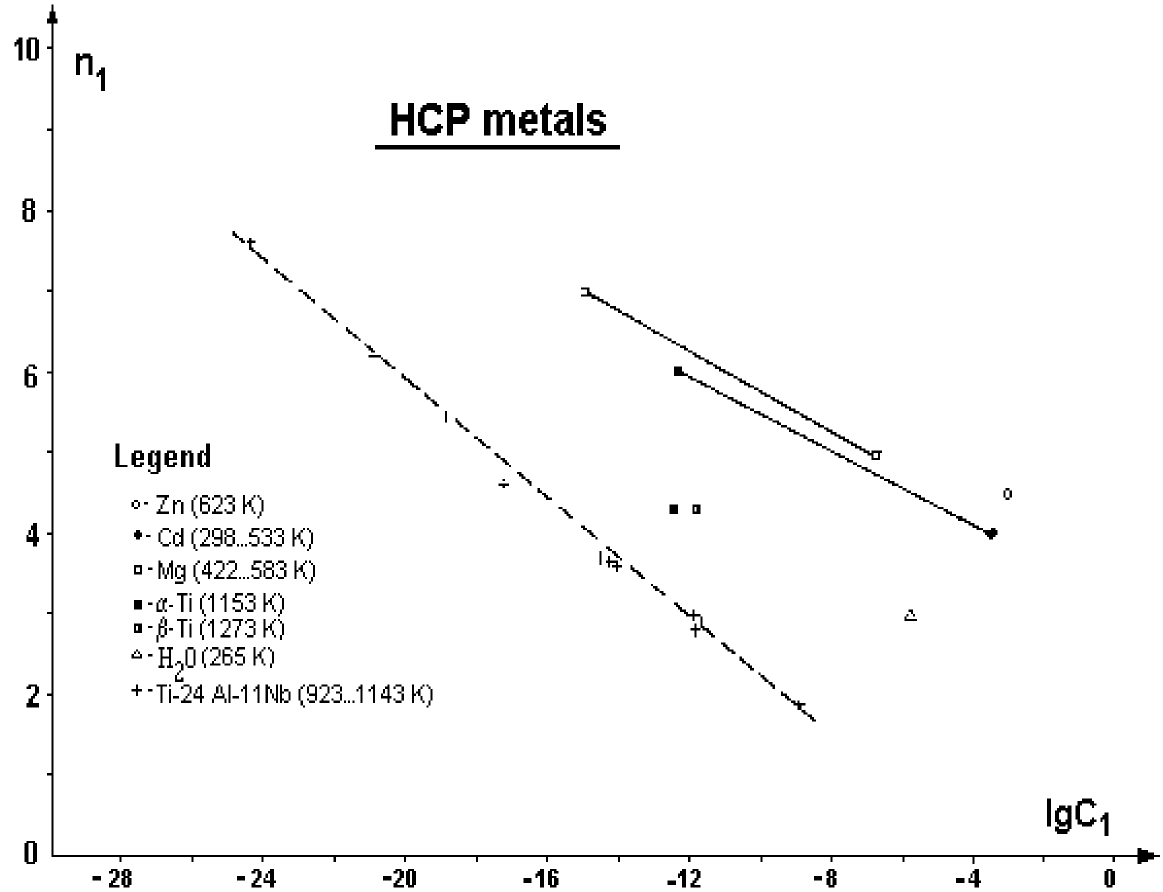

Fig. 5. Correlation between n_1 and lgC_1 parameters for steady creep rate of **HCP-**metals [stress in **MPa**, creep rate in **sec^{-1}**]

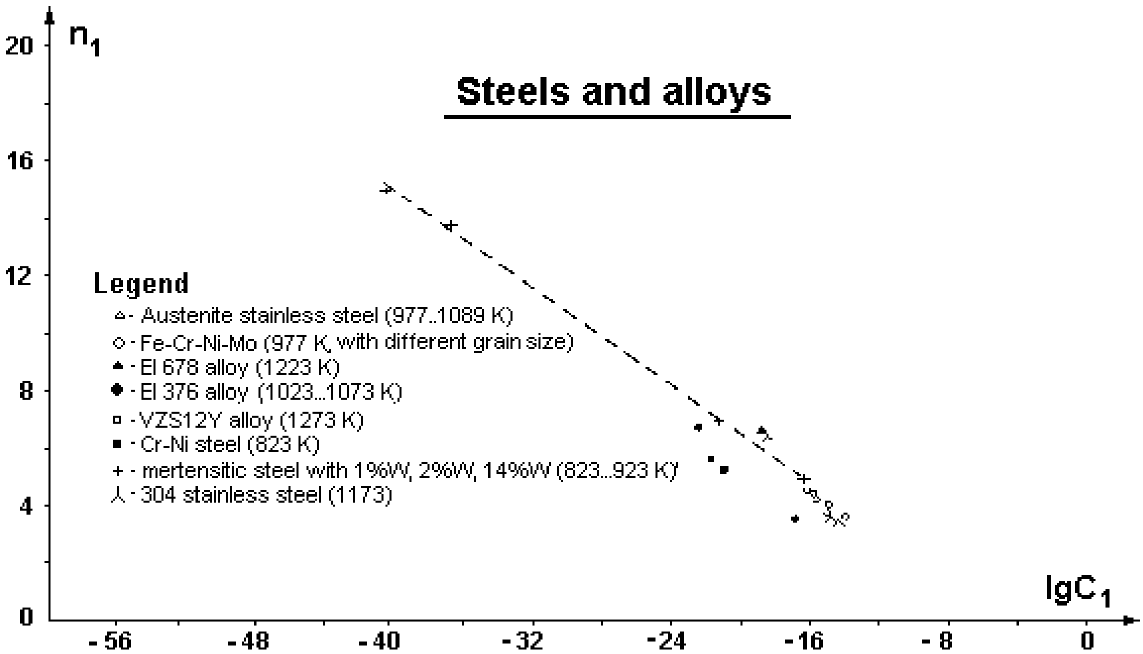

Fig. 6. Correlation between n_1 and lgC_1 parameters for steady creep rate of **STEELS** and **ALLOYS.** [stress in **MPa**, creep rate in **sec^{-1}**]

The same correlation can be observed between the parameters in equation of (3) i.e. Returning to the questions formulated in the introduction of this paper it can be stated that the material parameters in equations (2) -i.e. ***lgC₁*** and ***n₁*** and (3) -i.e. ***lgC'₁*** ‘ and ***n'₁***. are not independent. The question is now that have these correlation physical backgrounds or not, i.e. the correlation follows from the structure of power type of relationship.

FORMAL BACKGROUND OF THE CORRELATION

There is a general unit problem in equations of (2)-(4) because the constants of C_i always include the value of exponents as well. To eliminate this unit problem a better form of equation (1) is its normalised one

$$y=B(x/x_0)^n \tag{5}$$

where the x_0 value is a constant. In this case the units of **y** and **B** are the same**.** Considering this situation, there is an obvious connection between **C** and **n** in equation (1) if $x_0 \neq 1$. It follows from the comparison of relationships (1) and (5) that

$$C=B/x_0^n \text{ and } lgC=lgB+nlgx_0 \tag{6}$$

It can be seen that **C** and **n** values are independent only if $x_0 \equiv 1$. Each figure shows data where $x_0=1$!!!!. From this it follows that there is no formal background for the correlation observed.

PHYSICAL BACKGROUND OF THE CORRELATION

Considering that a damage process developed in the material during testing which can be described by using an equation of thermoactivated processes, it can be demonstrated that connections need to exist between the **C** and **n** material characteristics in equations (2)-(4).

The time to fracture (t_t) using the ZHURKOV assumption can be expressed by

$$t_t=t_o\exp[U(\sigma)/kT] \tag{7}$$

where

- t_o - is constant and independent of the temperature, material and other circumstances ($t_o=10^{-12}$-10^{-13}) **s**,
- $U(\sigma)$ - the activation energy (the driving force of the fracture),
- k - the Boltzman constant,
- T - temperature.

To describe the connection of the activation energy and **σ,** plenty of can be found in the literature. The most simple and widely used is

$$U(\sigma)=U_o\ln(\sigma/\sigma_o) \tag{8}$$

where

- U_o - the energy of barrier height,
- σ_o - the stress of inactivated part,
- σ - the applied stress.

It is obvious that the values of $\mathbf{U_o}$ and $\boldsymbol{\sigma_o}$ are different for different testing methods and loading conditions of the same material. Substituting equation (8) in (7)

$$t_t=[t_o(\sigma_o)^{Uo/kT}][\sigma^{-Uo/kT}] =C_1\sigma^{-n} \quad (9)$$

which is identical with expression (2). Because the values of $\mathbf{U_o}$ and $\mathbf{t_o}$ and $\boldsymbol{\sigma_o}$ are constant, a connection needs to exist between **C** and **n** which has the form of

$$\ln C= \ln t_o+n \ln\sigma_o \quad (10)$$

where

$$n=U_o/kT \quad (11)$$

Regarding equation (3), where the creep rate is expressed as a function of the stress the following can be used. The creep rate as a thermoactivated process which can be described by

$$\varepsilon=\varepsilon_o\exp [-Q(\sigma)/kT] \quad (12)$$

where

- ε_o-constant,
- $Q(\sigma)$- activation energy,
- k and T- the Boltzman constant and the temperature, respectively.

Substituting equation (8) -in which the stress of inactivated part is characterised by σ_o*- in (12), and taking its logarithm

$$\ln(\varepsilon)=\ln(\varepsilon_o)+(Q_o/kT)\ln(\sigma_o^*)-(Q_o/kT)\ln(\sigma) \quad (13)$$

The first two components of equation (13) is **lnC** in relationship (2), and the last is proportional to the exponent of $\boldsymbol{\sigma}$, i.e.

$$\ln C=\ln(\varepsilon_o)+(Q_o/kT)\ln(\sigma_o^*) \text{ and } n=(Q_o/kT) \quad (14)$$

It can be seen that a correlation between the **C** and **n** values needs to exist.

The physical background of $\mathbf{U_o}$, $\mathbf{t_o}$, $\boldsymbol{\sigma_o}$ or $\boldsymbol{\varepsilon_o}$, $\mathbf{Q_o}$, $\boldsymbol{\sigma_o}$* needs to be discussed in more.

SUMMARY

On the basis of the collected experimental data and the proposed approaches, the following conclusions can be drawn:

1. There exists a close correlation between the logarithm of the constants and exponents in power type relationships having two parameters (in equations 2 and 3) used to evaluate the creep testing results. This statement is experimentally verified.
2. These correlation are not the consequences of the structure of power type relationships.
3. The correlation have physical meanings based on thermally activated damage processes.

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