Acta Universitatis Carolinae. Mathematica et Physica

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*Acta Universitatis Carolinae. Mathematica et Physica*, Vol. 32 (1991), No. 1, 17--23

Persistent URL: `http://dml.cz/dmlcz/142623`

# Experimental Evaluation of the Strain Rate Sensitivity Parameter for Superplastic Materials

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*Received 27 August 1990*

## 1. Introduction

The most important characteristic of the superplastic materials [1–3] is the strain rate sensitivity which can be defined by:

$$m = \left.\frac{\partial \ln \sigma}{\partial \ln \dot{\varepsilon}}\right|_{\varepsilon, T} \tag{1}$$

Because of its importance a lot of experimental method was developed for the determination of the strain rate sensitivity [4].

The main purpose of this paper is to present a new possibility for the evaluation of the strain rate sensitivity parameter from tensile measurements and to show that the impression creep test is suitable for the determination of this parameter. The results are compared to those obtained by the conventional methods.

The strain rate sensitivity can depend on many parameters, for example the strain, strain rate, the temperature and some structural characteristics of the material. Besides, some effect of the experimental procedure is also involved into the measured value of the strain rate sensitivity parameter. In this paper some of these effects are discussed too.

### 1.1 Conventional methods

It is possible to assess $m$ directly from the double logarithmic plot of the stress-strain rate relationship which can be determined from a series of tensile tests of individual specimens. In this way the well known sigmoidal type curve of the stress-strain rate function for superplastic materials is obtained. According to definition the slope of this curve is the strain rate sensitivity parameter. For the sake of brevity in the following this method will be called direct method. A deformation process can be regarded as superplastic if $m > 0.3$.

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The determination of the stress-strain rate function by tensile creep measurements is very time-consuming and needs many specimens. To avoid these problems some other methods were also developed.

### 1.2. The strain rate change method

The most often used method for the determination of the strain rate sensitivity is the strain rate change method. According to this method during a tensile test with constant strain rate (or cross head velocity) a quick change in the velocity is applied. The strain rate sensitivity can be determined by the formula:

$$m \approx \frac{\Delta \ln F}{\Delta \ln v}$$

In the following this method will be called jump method.

Detailed investigations [5, 6] show that the experimental values obtained by this method depend strongly on the magnitude of the applied strain rate increment (or more exactly on the strain rate ratio) [7].

## 2. Estimation of m on the basis of only one stress-strain curve

The mechanical properties of a lead-tin eutectic alloy — as a reference material —, and Al — 4.8Zn — 1Mg alloys with Zr and Fe additions were investigated by tensile tests with constant cross head velocities. The force-elongation curves obtained were transformed into true stress-true strain curves with the help of the volume constancy. Typical stress-strain curves for superplastic deformation are shown in Fig. 1. The curves are very similar to each other and have a pronounced maximum character.

In a previous paper [8] it has been shown that the stress-strain and the force--elongation curves can be divided into three stages characterized by different stability

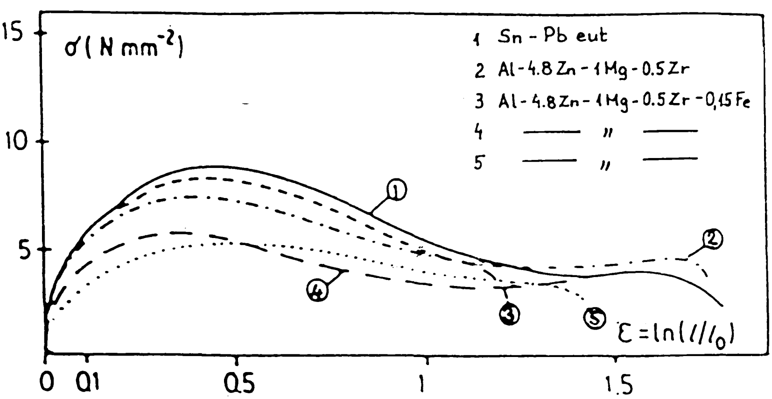


*Fig. 1.*

criteria. These stages are schematically shown in Figs. 2 and 3. The superplastic part of the elongation occurs in the third stage of the deformation process, which is characterized by the stability condition $d\sigma/d\varepsilon = 0$. The decrease of the flow stress

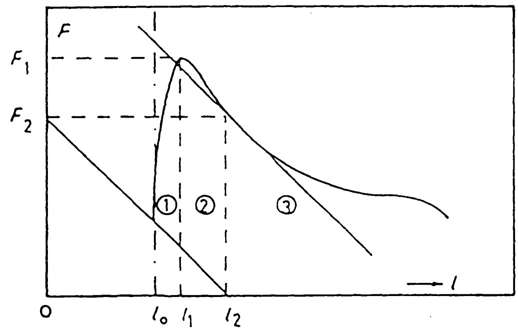


*Fig. 2.*

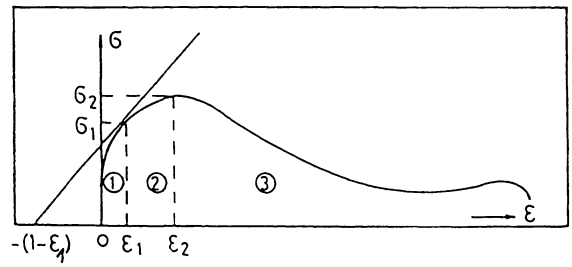


*Fig. 3.*

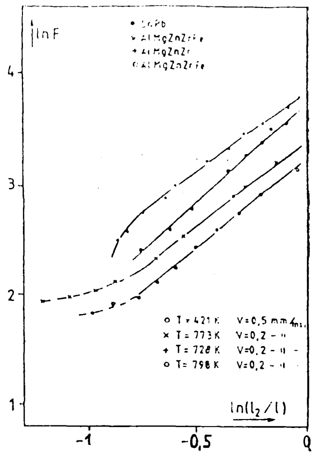


*Fig. 4.*

in Fig. 3. is a consequence of the decreasing strain rate ($\dot{\varepsilon}$). It was also shown previously [8] that this part of the force elongation curve can be described by the formula:

$$F = F_2(l_2/l)^{m+1} \tag{3}$$

where $F_2$ and $l_2$ are the coordinates of the initial point of the third stage in a force elongation plot. It means that replotting the experimental data in the form of a $\ln F -$ $- \ln (l_2/l)$ function the strain rate sensitivity can be evaluated from the slope of the straight line obtained. Fig. 4. shows these straight lines the slope of which gives $m+1$ for different alloys at various temperatures. It can be shown that if the deformation is not superplastic then this procedure does not lead to straight lines, therefore the m values obtained above characterize only the superplastic process.

The $m$ values determined by this method agree well with those obtained by the jump method at $\varepsilon \approx \varepsilon_2$ where $\varepsilon_2$ corresponds to the maximum streess and it is the initial point of the third stage. From this agreement we can conclude that even if conventional methods is used, the strain rate sensitivity parameter is to be determined at strains higher than $\varepsilon_2$.

## 3. Impression creep test methods

The mechanical properties of the superplastic alloys can also be investigated by impression creep test. In the course of the impression creep test a cylindrical flat ended punch is pressed continuously into the surface of the sample and the impression depth is recorded as a function of time. According to experimental evidences the velocity of the punch after a short time becomes constant [9].

There are both theoretical and experimental evidences [10–12] that in order to compare this test with the tensile one the impression data must be converted to equivalent stress and equivalent strain rate by the formulae

$$\sigma = \frac{p}{3}, \left( p = \frac{F}{\frac{d^2}{4}\pi} \right); \quad \dot{\varepsilon} = \frac{v}{d}$$

where $d$ is the diameter of the punch.

This means that the strain rate sensitivity can be determined from impression creep data by analogous method to those of tensile tests.

The direct method can be applied in the same way as in the case of a tensile test. To demonstrate this fact a series of stress-strain rate curves obtained by impresion method are shown in Fig. 5. (The tests were performed in a self-made equipment the detailed description of which was published elsewhere [9]).

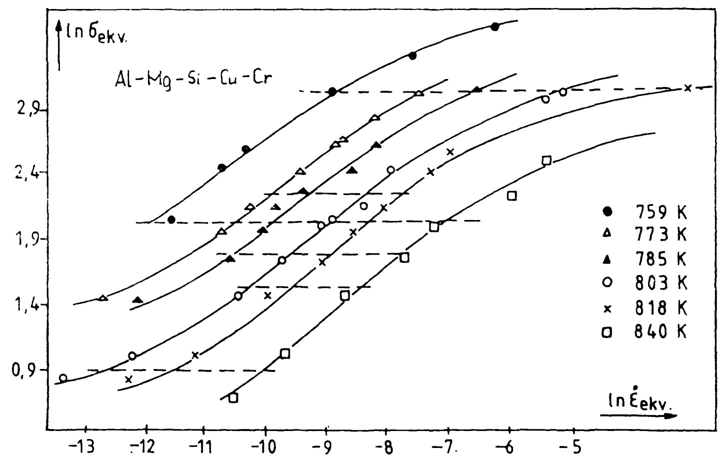


*Fig. 5.*

Using the jump method instead of the direct velocity change a load jumps is applied during the steady state stage of the deformation by which the strain rate sensitivity can be determined in the same way as in the case of the tensile test by the formula:

$$m = \frac{\Delta \ln F}{\Delta \ln v} = \frac{\Delta \ln p}{\Delta \ln v}$$

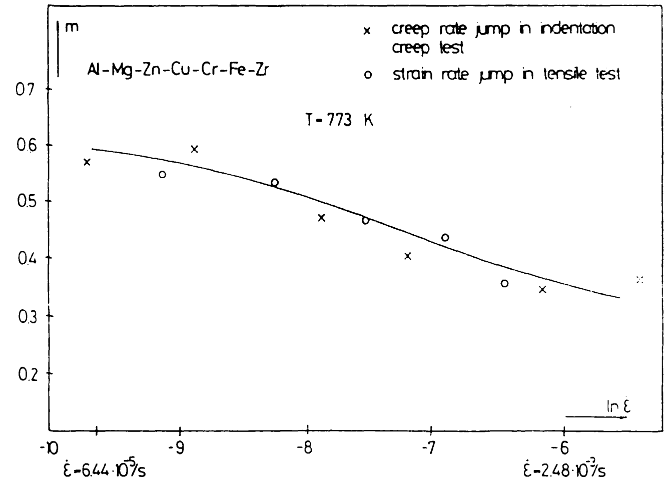


*Fig. 6.*

Fig. 6. shows the *m* values determined by tensile tests and by impression creep tests with the jump method for an Al-Mg-Zn-Zr alloy. The velocity ratio in the tensile test was 2 and the load jump for the impression test was choosen so that the velocity ratio let be between 1 and 2. The results obtained by the two different methods agree well.

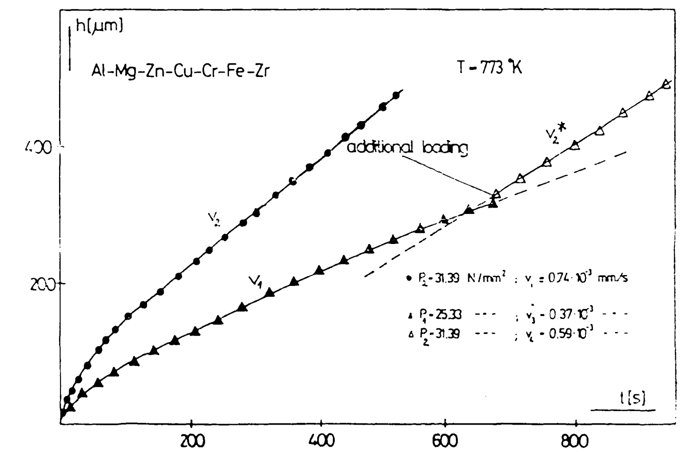


*Fig. 7.*

### 3.1 The effect of the load jump

It is a general experience that the impression velocity, $v_2^*$ taking place after a load jump $F_1$ to $F_2$ is lower than the v observed in the course of a creep test with constant $F_2$ load (Fig. 7.). A direct consequence of this fact is that the strain rate sensitivities obtained by the jump method are higher than that assessed by the direct method. Experimental results show, however, that the higher the load jump (or the velocity ratio) is the lower the deviation between the results of the two methods. Fig. 8. shows the variation of the strain rate sensitivity with the velocity ratio.

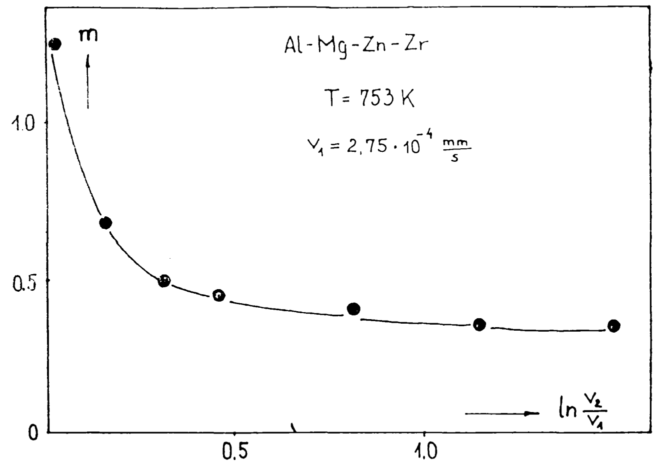


*Fig. 8.*

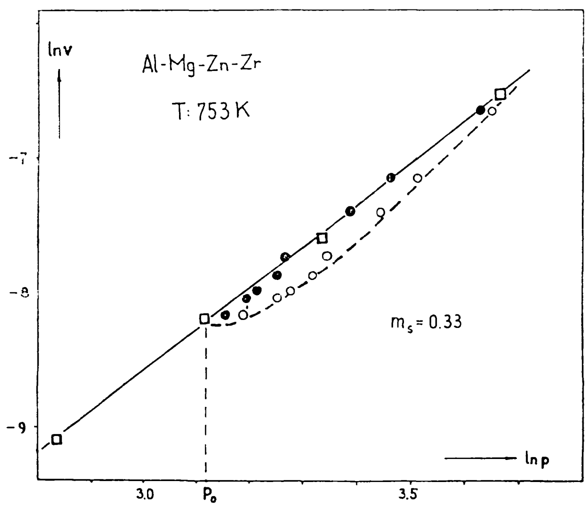


*Fig. 9.*

The effect of the load (or velocity) jump was investigated in details, too. The pressure-velocity function was obtained by individual creep experiments. It is shown in Fig. 9. by the continuous line. A series of creep experiments with load jumps were also performed. Every test was started by the same pressure, $p_0$, but in the course of the steady state stage the pressure was increased to different $p^*$ stress levels and the new steady state $v^*$ velocities were recorded. The dashed curve in Fig. 9. lies along the points due to creep tests with different pressure (load) jumps.

The relationship between the pressures $p$ and $p$ necessary to reach the same indentation velocity in the creep tests with and without load jump can be described by the formula obtained experimentally:

$$p = p^* - \beta \frac{\Delta p}{p^{*5}} \tag{4}$$

where $\Delta p = p^* - p_0$ and $\beta = 6.1 \times 10^6\ (\mathrm{N/m^2})^5$. In Fig. 9. the points denoted by squares correspond to this formula. They fit well to the pressure-velocity curve. It means that with the help of equation (4) the pressure-velocity function obtained by pressure jumps can be converted to that due to constant loads.

## 4. Conclusions

1. In the case of superplastic materials the strain rate sensitivity can be evaluated using a single force-elongation curve.

2. To study the strain rate sensitivity the impression creep tests lead to equivalent results with those of the tensile tests.

3. The strain rate sensitivities obtained with jump methods depend strongly on the load jump (or the velocity ratio) and they are in general higher than those measured by the direct method.

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