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CREEP AND ISOCONFIGURATIONAL FLOW OF METGLAS 2826A

A.L. Mulder, J.W. Drijver and S. Radelaar

Department of Technical Physics, University of Utrecht, P.O. Box 80.000, 3508 TA Utrecht, The Netherlands

Introduction. - Because of the possible application of metallic glasses in energy storing devices a number of their properties has been studied in our laboratory. Results concerning energy storing flywheels /1,2/ and the storage of hydrogen /3/ have been published before.

In this study we report on the creep properties of Metglas 2826A with the emphasis on the aspects of isoconfigurational flow conditions. The fundamentals of this concept were recently elaborated by Spaepen and Turnbull /4/ and Spaepen /5/.

Experimental. - As in our previous work Metglas 2826A was used in the present study. The alloy (Ni36Fe32Cr14P12B6 at.%.) was obtained from Allind Chemical in the form of ribbons approx. 2.1 x 0.06 mm² in size. The mean cross-sectional area of the specimens was calculated from their length and weight using a density of 7.46 x 10³ kg.m⁻³ /6/. X-ray diffractograms of random samples of as-received material did not show any signs of crystallinity. A comparison between DSC-scans of as-received material and specimens used for creep experiments confirmed that no crystallization had taken place during the creep experiments.

Creep experiments were performed on a constant-stress continuous-load creep apparatus which is provided with a gas bearing /7/ and an Andrade lever arm /8/. Elongation of the specimens was continuously measured by means of an LVDT with a resolution of 0.5 μm. Creep rates down to 10⁻¹⁹ s⁻¹ could be detected.

Samples of 100.0 mm length were creep tested while submerged in an oil-bath with a thermal stability of 0.1 K. Room temperature was controlled within 1 K. All measurements reported here (except for curve A in figure 1) were made on samples which were pre-annealed to stabilize the amorphous structure. Pre-annealing consisted of linear heating (60 K/hr) in situ to 568 K immediately followed by free cooling in situ to 323-333 K. During this relaxation treatment a small stress (25 MPa) is applied to the specimen to keep it straight. During linear heating of an as-received sample an irreversible decrease of length is observed. Repeated heating of the same temperature did not lead to any further shrinkage. It can thus be deduced that the relaxation treatment results in a well-defined amorphous structure.

The activation energy for isoconfigurational flow was determined after the establishing of steady state creep at 548 K. After stepwise (5-10 K) lowering of the temperature the steady state creep rates were determined for temperatures between 548 K and 503 K and stresses between 1000 MPa and 1600 MPa.

Results

Examples of creep curves of relaxed Metglas 2826A are presented in figures 1 and 2. If this data are plotted in an appropriate way the well-known features of the creep curves of crystalline solids appear. In the first part of the curves primary or transient creep is present in which the creep rate ε decreases with time t, then reaches a constant minimum value ε min in the region of the linear or steady state...
creep. In some cases also tertiary creep is observed before sample failure. In the region of primary creep the strain can be very well described by a power law
\[ \varepsilon \sim t^p \] (1)
as known to be usually valid for crystalline solids/9/. The time exponent \( p \) appears to be stress and temperature dependent as is shown in figure 3.

In the second part of the creep curves the steady state creep rate \( \dot{\varepsilon}_{\text{min}} \) can be described by the expression
\[ \dot{\varepsilon}_{\text{min}} = A \sigma^n \exp(-Q/RT) \] (2)
as used before by Gibeling and Mix/10/ for their analysis of creep data of Metglas 2826. In this formula the dependence of the stress \( \sigma \) is described by the stress exponent \( n \) and the dependence of the temperature \( T \) is described by an activation energy \( Q \) and Boltzmann's constant \( k \). By expressing \( \dot{\varepsilon}_{\text{min}} \) in the apparent viscosity \( \eta \) by use of the relation \( T/\eta = \sigma/3 \dot{\varepsilon}_{\text{min}} \), a plot can be made of \( \ln \eta \) vs. \( \ln 1/T \). The results for some stresses are depicted in figure 4. The slope of these curves yields the activation energy \( Q \) for isoconfigurational flow. \( Q \) was determined for a range of stress values between 1000 MPa and 1600 MPa as is presented in figure 5 (lower horizontal scale, 0). Within this stress range the mean value of \( Q = 250(\pm 10) \text{kJ mol}^{-1} \) and within the experimental uncertainty \( Q \) is independent of the stress. By measuring two creep curves at different temperatures \( (T_1, T_2) \) but at the same stress one can determine the times \( (t_1, t_2) \) in the steady state region for which identical strains are reached. The activation energy \( Q \) is then calculated from/11/
\[ Q = k \frac{T_2 - T_1}{T_2 - T_1} \ln \frac{t_1}{t_2} \] (3)
The results of such an analysis are presented also in figure 5 where this activation energy is plotted as a function of strain (upper horizontal scale, 0). The stress exponent \( n \) from (2) was determined from the slope of \( \ln \dot{\varepsilon}_{\text{min}} \) vs. \( \ln \sigma \) plots. Our value of \( n = 9.5 \pm 0.5 \) is independent of the temperature.

By using the creep data we constructed a part of the deformation map of pre-annealed Metglas 2826A. The result is presented in figure 6 for deformation rates ranging from \( 10^{-5} \text{ s}^{-1} \) to \( 10^{-9} \text{ s}^{-1} \). Inserted also are some unpublished tensile test results for unrelaxed Metglas 2826A.

Discussion
From a comparison between the curves A (as-received) and 1 (relaxed) in figure 1 it can be concluded that pre-annealing decreases the observed creep rates to a large extent, which was also observed for \( \text{Fe}_{82}\text{Si}_{18} \) by Taub and Spaepen/12/. Apparently the viscosity increases by the densification of the structure during the relaxation treatment.

Gibeling and Mix/10/ found a stress-dependent activation energy (150-200 kJ mol\(^{-1}\)) for Metglas 2826 (\( \text{Ni}_{50}\text{Fe}_{30}\text{Fe}_{10}\text{B}_{5} \)) which is also substantially lower. Our value of \( Q = 250 \text{ kJ mol}^{-1} \) agrees well with the activation energies for creep in crystalline \( \text{Ni} \) and \( \text{Fe} \) (243 kJ mol\(^{-1}\) and 256 kJ mol\(^{-1}\) respectively/11/).

In the determination of the activation energy the initial steady state creep was established at 548 K (0 in fig. 4). The possible influence of this treatment on the activation energy was checked by two ex-
tivation energy is independent of the way the initial steady state is reached. The values determined from figure 4 and from (3) are in reasonable agreement with each other. As mentioned e.g. by Scott /13/ the activation energy for viscous flow often agrees well with the activation energy for crystallization indicating that the configurational changes for flow and interface movement are similar. This agreement obviously holds also for Metglas 2826A. For the crystallization of the 1S-1 phase we determined (by DSC) a \( Q_{\text{cryst}} = 300-320 \text{ kJ mol}^{-1} \), von Heimendahl and Haussner published a value of 250-270 kJ mol\(^{-1}\) /14/. The value of our activation energies for isoconfigurational flow and steady state creep is fairly large. Spaepen /5/ expected the earlier values of the activation energy for creep to increase on annealing. Similar behaviour has been observed in stress relief kinetics e.g. by Pratten and Scott /15/. Using (3) we determined activation energies for creep of unrelaxed Metglas 2826A. These values of \( Q \) increase from about 100 kJ mol\(^{-1}\) to about 200 kJ mol\(^{-1}\) while being creep tested (and so annealed). In this regard one could speculate about the apparent increase of \( Q \) in our pre-annealed specimens as shown in figure 5 (upper scale, \( O \)). The slight increase of the activation energy with increasing strain (and so increasing annealing time) suggests that despite the pre-annealing treatment still some structural relaxation takes place during creep testing. Contrary to the findings of Gibeling and Mix /10/ our value of \( n = 9.5 \pm 0.5 \) is independent of the temperature. The value itself compares well with the \( n = 7-10 \) determined by these authors for Metglas 2826.

As can be seen in figure 6 the results of tensile testing are in good agreement with the creep results. The strain rates were obviously low enough to obtain a comparable amount of structural relaxation at the time (20 h) the maximum stress in the horizontal part of the stress-strain curves was observed.

![Fig. 6. Part of the deformation map constructed from steady state creep (\( A \)) and tensile test (\( O \)) data (see text).](image)

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**References**


/4/ F. Spaepen and D. Turnbull in Metallic Glasses, ASM, Ohio, 1978


/7/ Design kindly supplied by SKF Engineering and Research Centre B.V.


/14/ M. Von Heimendahl and G. Maussner, ibid, 424.

/15/ N.A. Pratten and M.G. Scott, ibid, 387.