acta phys. slov. 43 (1993), No. 6, 431–440

CREEP BEHAVIOUR OF Al - 10WT % Zn ALLOY WITH DIFFERENT GRAIN DIAMETERS IN THE HIGH STRESS REGION

S.B. Youssef, A. Fawzy, M. Sobhy, G. Saad

Department of Physics, Faculty of Education,
Ain Shams University, Cairo Egypt

Received 17 May 1993, in final form 26 July 1993
Accepted 30 July 1993

Creep properties of Al - 10wt % Zn alloy were studied using specimens of different grain diameters in the high stress range 163–193 MPa. The transient parameter n, was found to increase with increasing grain diameter. A decrease in the steady state creep rate was obtained by increasing grain diameter according to a Petch style relation. In this high stress region, the stress exponent m, increases with grain diameter. This was explained as due to the transition in climb velocity of dislocations from a linear to an exponential function of stress.

I. INTRODUCTION

Continued creep at constant stress results from simultaneous action of work hardening and recovery. Work hardening is relatively well understood. However, in spite of many efforts an adequate understanding of the complicated processes by which dislocations rearrange and finally disappear from the material during recovery is still lacking [1–3]. In order to get better understanding of this situation it is reasonable to identify the different mechanisms of dislocation motion taking part in creep.

While most of the creep literature deals with determinations of the steady state creep rate, there are comparatively few investigations on the effect of stress changes. Following later reviews [4–6] the creep behaviour of solid solution alloys is divided into two classes according to the value of the stress exponent m. For class I alloys, m has a value of ~ 3, while for class II alloys m is similar to that of pure metals and is close to 5. However, at high normalized stresses ($\sigma/G > 10^{-4}$), where σ is the applied normal stress and G is the shear modulus, the creep rates increase rapidly with stress to higher values ($m > 8$) [7].

According to Sherby and co-workers [8] the stress sensitivity of the creep rate of Al, at constant dislocation structure, is given by a power law with a stress exponent of 8 in the range of low stresses, where the steady state of creep obeys a power law. Blum and co-workers [9,10] described the creep rate of Al Zn at constant structure by an exponential stress dependence. An exponential stress dependence was also found for pure Al by Yaney et al [11].

In the present work it was found worthy to study the effect of grain diameter on both the transient and steady state creep at high normalized stresses ($\sigma/G > 10^{-4}$). The validity of the stress power law as well as the value of the stress exponent m were also investigated at these high normalized stress level.

II. EXPERIMENTAL PROCEDURE

2.1. Material Preparation

Al-10%Zn was produced from pure Al and Zn (99.99). Both elements were ultrasonically cleand for 10 min each in its proper solution [12] which etched away the surfaces and reduced the possibility of contamination. Al and Zn were weighed and placed in an alumina crucible with a cover. This charge was then heated in a box furnace to a temperature approximately 50° C above the melting point of the alloy. By melting slowly at this temperature and using a covered crucible it was found that the loss of Zn due to its high vapour pressure could be reduced. Casting was done in a graphite mold. The rod thus obtained of 12 mm in diameter was reduced to wire of 0.35 mm with appropriate intermediate annealing treatment.

Chemical analyses were made on specimens taken from different parts of the cast. It was determined that the deviation in composition was less than 0.5 wt%Zn.

2.2. Mechanical test

Creep tests were conducted with a constant load locally made creep machine. Details of the creep testing equipment have been published elsewhere [13].

All creep tests were conducted in tension and in air at room temperature (300 K). Before testing, the specimens were prelimenary annealed in the solid solution range for *1 h* at the temperatures 573, 673, 773 and 873 K then immediately quenched in water at room temperature. Specimens of average grain diameters 14, 20, 24 and 30 μm, as determined optically by the line intercept method by measuring approximately 50 intercepts, were obtained by this heat treatment. The creep tests were performed at the stresses 163, 173.3, 183.4 and 193.5 MPa by loading the test wire of the same grain diameter with the corresponding loads. The extension in the wire during creep was measured optically using a travelling microscope with an accuracy of 10^{-4}cm. Not less than three creep tests were repeated for each grain diameter. Reliable and reproducible results were obtained.

2.3. Experimental Results And Observations

Strain-time curves for specimens having grain diameters of 14, 20, 24 and 30 μm under different applied stresses 163, 173.3, 183.4 and 193.5 MPa are shown in Fig. 1. From Fig. 1 we see that Al - 10% Zn exhibits normal creep behaviour.

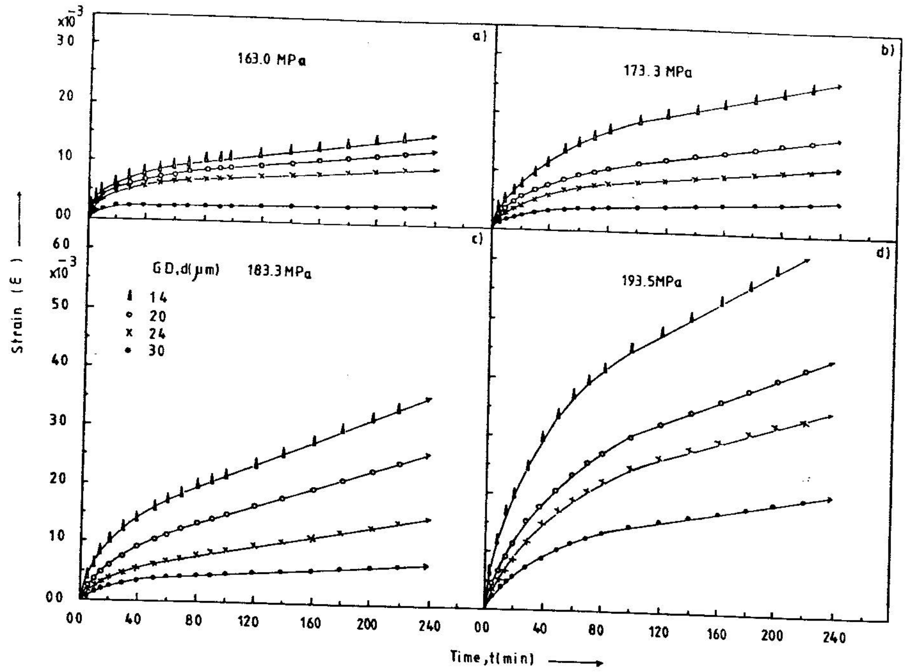

Fig. 1. Strain-time curves at room temperature for Al - 10wt % Zn wires with different grain diameters as indicated at stresses: (a) 163, (b) 173.3, (c) 183.3 and (d) 193.5 MPa.

The creep curves consist of a transient stage with decreasing creep rate, a steady state stage with constant creep rate which lasts up to a creep time of more than 4 hours. In the present experiments we did not reach the specimen failure.

(a) - Transient Creep. The straight lines in Fig. 2 are plots of the logarithm of the transient strain $\ln \varepsilon_{tr}$ against $\ln t$ for the above different grain diameters at the different applied stresses. The time exponent n in the transient creep equation $\varepsilon_{tr} = kt^n$ was obtained from the slopes of the lines in Fig. 2. The results showed that n ranged between 0.55 and 0.99 depending on the applied creep test conditions (grain diameter and applied stress). Fig. 3 illustrates n as a function of the grain diameter. ¿From Fig. 3 it is clear that at a given applied stress, n increases by increasing grain diameter. The parameter k in the transient creep equation was obtained from the intercept at $\ln t = 0$ in Fig. 2. It was found that k depends on the grain diameter as well as on the applied stress. This dependence is shown in Fig. 4, from which it is clear that k decreases by increasing grain diameter.

(b) - Steady - State Creep Rate $\dot{\varepsilon}_s$. The steady state creep rates $\dot{\varepsilon}_s$ as obtained from the slopes of the linear parts of the strain-time curves shown in Fig. 1, were

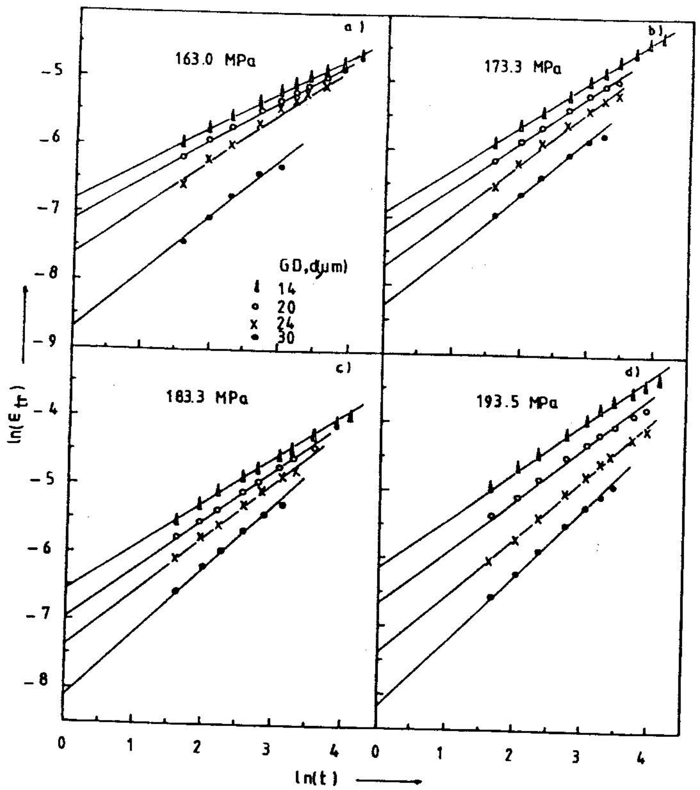

Fig. 2. Relation between $\ln \varepsilon_{tr}$ and $\ln t$ for Al - 10wt % Zn wires with different grain diameters and stresses as indicated.

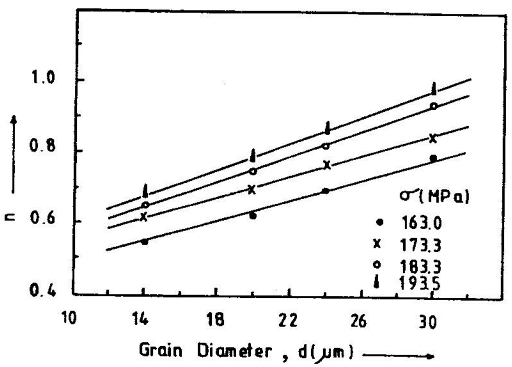

Fig. 3. The dependence of the transient creep exponent n on the grain diameter d at different stresses as indicated.

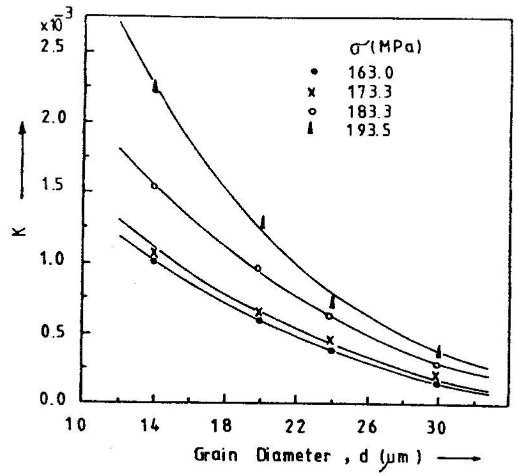

Fig. 4. The dependence of the transient creep parameter k on the grain diameter d, at different applied stresses as indicated.

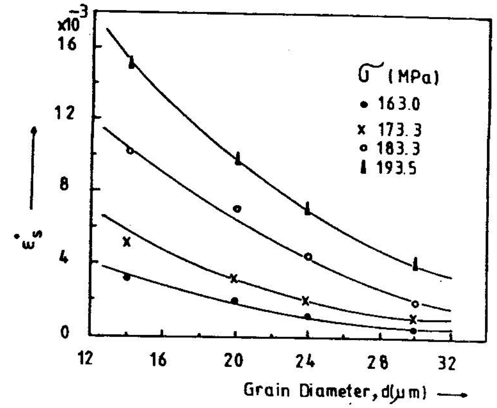

Fig. 5. The effect of grain diameter d on the steady state creep rate $\dot{\varepsilon}_s$, at different stresses as indicated.

found to depend on both the grain diameter and applied stress. Fig. 5 depects $\dot{\varepsilon}_s$ as a function of the grain diameter at different values of applied stresses σ. From this figure, it is clear that $\dot{\varepsilon}_s$ decreased with a decreasing rate by increasing grain diameter for all applied stresses.

The steady state creep rates $\dot{\varepsilon}_s$ are presented in Fig. 6, from which it is seen that $\dot{\varepsilon}_s$ values satisfy the relation $\dot{\varepsilon}_s = a\sigma^m$. The stress exponent m introduced in the above equation is found grain diameter dependent as shown from Fig. 7,

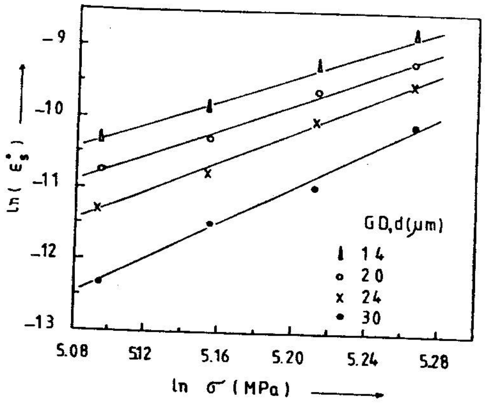

Fig. 6. $\ln \dot{\varepsilon}_s$ versus $\ln \sigma$ for Al - 10wt % Zn wires with different grain diameters as indicated.

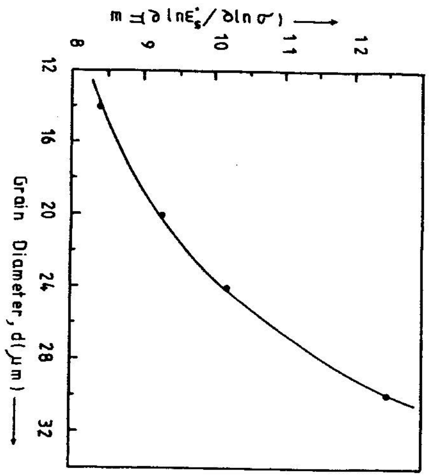

Fig. 7. Grain diameter d versus stress exponent $m (= \partial \ln \dot{\varepsilon}_s / \partial \ln \sigma$ at different stresses as indicated.

indicating that m increases by increasing grain diameter. The value of m obtained in the range of grain diameter we used varies from 8.4 up to 12.5.

III. DISCUSSION

3.1. Transient Creep

¿From Fig. 3, it is to be noticed that n increases with increasing both grain diameter and applied stress. The parameter n determines the dependence of the

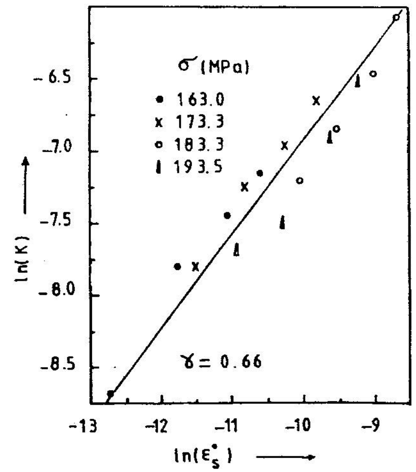

Fig. 8. The variation of transient creep parameter k with the steady state creep rate $\dot{\varepsilon}_s$.

mobile dislocation density ρ on the value of the mean internal stress σ_i and the relaxed shear modulus [14,15] G, according to the relation $\rho = \sigma_i^2/(nGb)^2$, where b is the Burgers vector of the dislocations involved. It is to be noticed that increasing grain diameter will result in the decrease of the dislocation density ρ and since the internal stress σ_i is a small faction of the applied stress it may be considered that σ_i is constant at high stresses [16]. So the increase of grain diameter will result in the increase of the transient creep parameter n.

In order to correlate between transient and steady state creep, values of $\ln k$ versus $\ln \dot{\varepsilon}_s$ for different grain diameters were plotted as shown in Fig. 8. A linear dependence was obtained irrespective of the applied stress and the relation $k = k_0 \dot{\varepsilon}_s^{\gamma}$ was thus proved to be valied with the exponent γ having an average value of 0.66. The dependence of the steady state creep rate $\dot{\varepsilon}_s$ on the transient creep parameter k seemed to be induced by the decrease of dislocation density which is proposed to enhance the transient and steady state creep.

3.2 Steady State Creep

It is well established [17] that the creep rate dependence on the grain diameter differs according to the type of annealing used to obtain the different grain diameters. When different grain diameters are obtained with minimum grain growth such that misorientation of grain boundaries is randomly distributed, the steady state creep rate $\dot{\varepsilon}_s$ should increase with increasing grain diameter because of the decrease of the boundary barriers to dislocation. On the contrary, $\dot{\varepsilon}_s$ decreases by increasing grain diameters when the later are produced by grain growth method. This is because large grain diameters are poor sources of vacancies leading to a low dislocation climb rate.

The observed decrease in the steady state creep rate with increasing grain diameter at constant stress (see Fig. 5) could be explained on the basis that a

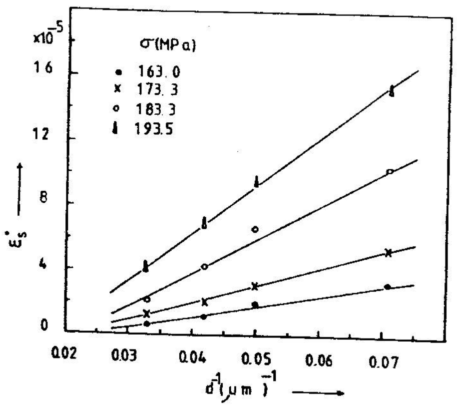

Fig. 9. Relationship between the strain rate $\dot{\varepsilon}_s n$ and the reciprocal of the grain diameter d at various stresses as indicated.

redistribution process of the solute atoms (Zn) may take place in the solid solution matrix [18]. In this respect point defects (vacancies and / or impurities) [18] with high concentration - depending on the annealing temperature - concentrate around the moving dislocation lines impeding their motion and leading to the decrease of $\dot{\varepsilon}_s$. The increase of grain diameter is associated with an excess number of vacancies. These vacancies act as pinners and in addition to the solute atoms, may account for the further decrease of $\dot{\varepsilon}_s$ with increasing grain diameter. The relation between the steady state creep rate $\dot{\varepsilon}_s$ and the reciprocal of the grain diameter is represented in Fig. 9. This linear dependence can be expressed by the emperical relation $\dot{\varepsilon}_s = \dot{\varepsilon}_0 + bd^{-1}$, where b and $\dot{\varepsilon}_0$ are constants depending on the stress and grain diameter range under investigation, respectively. This equation is to some extent similar to that privously used by Petch [19] and Hall [20].

In pure metals and metal type (class II) alloys, the creep rate in the power law region is controlled by the climb of dislocation [4]. In the present work the validity of the power - law creep was checked and it was found that $\log \dot{\varepsilon}_s$ linearly related with $\ln \sigma$ for specimens of different grain diameters. Unexpected large values ranged from 8.5 up to 12.5 for the stress exponent m depending on the grain diameter were obtained. The value of m increased with increasing grain diameter as shown in Fig. 7. This large values of m may be explained from our point of view as due to the transition in climb velocity of dislocations from a linear to an exponential function of stress as that level used. This breakdown in power law is expected when the stress reaches a value that the dislocations can break a way from their solute atmospheres [21,22].

REFERENCES

[1] W. Blum : Scripta Metall, *18* (1984), 1383.

[2] D. Caillard , J.L. Martin : Rev. Phys. Appl., *22* (1987), 169.

[3] U.F. Kocks : Dislocation and Properties of Real Materials, Inst. of Metals London (1985), 125.

[4] O.D. Sherby , P.M. Burke : Prog. Mater. Sci., *13* (1968), 325.

[5] W.R. Canon , O.D. Sherby : Metall. Trans., *1* (1970), 1030.

[6] F.A Mohamed , T.G. Langdon : Acta Metall., *22* (1974), 779.

[7] S. Soliman Mahmoud : J. Mater. Sci., *22* (1987), 3529.

[8] O.D. Sherby , R.H. Klundt , A.K. Miller : Metall. Trans., *8A* (1977), 843.

[9] G. Köning , W. Blum : Acta Metall., *25* (1977), 1531.

[10] W. Blum , A. Finkel : Acta Metall., *30* (1982), 1705.

[11] D.L. Yaney , J.C. Gibeling , W.D. Nix : Acta Metall., *35* (1987), 1391.

[12] B.A. Chin , G.M. Pound , W.D. Nix : Metall. Trans., *8* (1977), 1517.

[13] G. Saad , G. Graiss , A. Fawzy : Ind. J. Pure and Appl. Phys., *29* (1991), 344.

[14] J.J. Gilman : J. Appl. Phys. (U.S.A.), *36* (1985), 2772.

[15] J.W. Edington , R.E. Smallman : Acta Metall. (U.S.A.) *12* (1964), 313.

[16] A. Arieli , A.K. Mukherijee : Creep and Fracture of Engineering Materials and Structures, edited by Wilshire B., Owen D.R.J. (Pineridge Press, Swansea, 1981) P.97.

[17] E.R. Parker : Proc. Am. Soc. Testing Mater., *60* (1960), 849.

[18] G. Saad , F. Abd El-Salam , M.T. Mostafa : Surface Technology, *22* (1984), 73.

[19] N.J. Petch : J. Iron Steel Inst., *174* (1953), 25.

[20] E.O. Hall : Proc. Phys. Soc., *64* (1951), 747.

[21] J. Weertman : *Rate Processes in Plastic Deformation of Materials.* Edited by J.C.M.L., Mukherjee A.K. (ASM, Metal Park, Ohio, 1975) p 315.

[22] F.A. Mohamed : Mater. Sci. Eng., *38* (1979), 73.