Transient and steady state creep of Pb – 20 wt % Bi during phase Transformation

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The transient and steady state creep of Pb –20wt. % Bi alloy have been investigated using various stresses ranging from 4.5 MPa to 7 MPa in the temperature range from 343K to 423K in steps of 10 K. The purpose of this study is to explore the behavior of this alloy under different temperatures during the transformation. Our results show that the transient creep parameters n and β increased extensively with increasing the deformation temperature and exhibited peaks at 363 K. This behavior illustrates the main processes that associated with the release of the stored deformation energy including the redistribution and rearrangement of the dislocations in the network at transformation. The relation between the transient creep parameter β and the steady state creep rate ξ_{st} gives the exponent (γ) which ranges from 0.67 to 0.70, characteristic in the temperature region from 363 K to 383 K might be attributed the dislocation of β - phase. The peak value of strain rate sensitivity parameter m of the steady state creep was 0.66. The activation energies obtained near and after the phase transformation were found to be 0.065eV to 0.65eV for transient creep and 0.26eV to 0.65eV for steady state creep in low and high temperature ranges, respectively. These values characterized dislocation cross–slipping and dislocation climb as rate controlling mechanisms for creep in this alloy

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Introduction

Crystalline metals and alloys, which have High elongations under small-applied loads, are known as super – plastic materials [1]. Super plasticity is a phenomenon where materials show high ductility without sharp necking [2,3]. Structural superplasticity cannot be applied basically to a certain class of materials such as the advanced single crystals or directionally solidified superalloyes. So, another type of superplasticity termed the internal stress superplasticity should be considerd [4]. When a small external stress is applied to some types of materials under a thermal cycling condition, they possess high internal stresses and deform superplastically with an average strain rate propertional to the applied stress. This linear relationship which is known as internal stress superplasticity [5,6], has been also observed in materials undergoing phase transformation [7]. Lead is a soft, melleable and ductile metal. Solid solubility of a metal in Pb changes its strength and ductility during phase transformation. The alloy under investigation (Pb-20wt%Bi) was studied before with special interest in structure and electrical properties [8,9,10]. Its mechanicel properties were rarely investigated, especially, the effect of phase transformation on transient creep. Steady state creep characteristics depend mainly on the working temperature, the applied stress, and the microstructure of the test sample [11]. The aim of the present work is to study the transient and steady state creep deformation and the micro-structural properties of this alloy during phase transformation. The following relation gives the dependence of the strain rate on the applied stresses is ;

$$\sigma = K\,\xi^{m} \qquad (1)$$

Where σ is the applied stress, and ξ is the strain rate. K is constant and m is the strain rate sensitivity parameter, and both parameters depend on the testing conditions [12], The transient creep is represented by.

$$\xi_{tr} = \beta\, t^{n} \qquad (2)$$

Where β and n are the transient creep parameters, t is the creep time in seconds. It can be mentioned that a marked dependence of β on the strain rate of the steady state was previously represented by [13,14], that is:

$$\beta = \beta_o\,(\xi_{st})^{\gamma} \qquad (3)$$

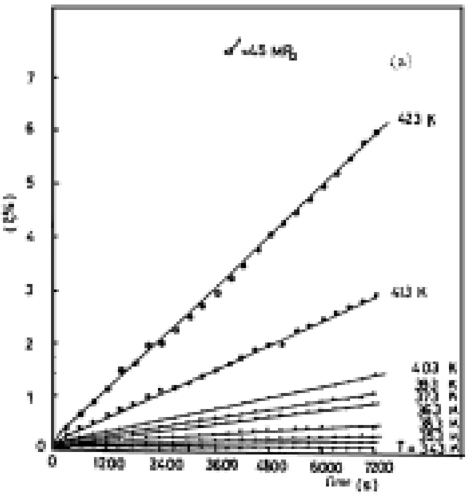
Where β_0 is constant and the exponent γ depends on the experimental conditions. In fact this work is concerned primarily with the investigation of creep deformation of Pb-20wt. %Bi alloy during phase transformation*

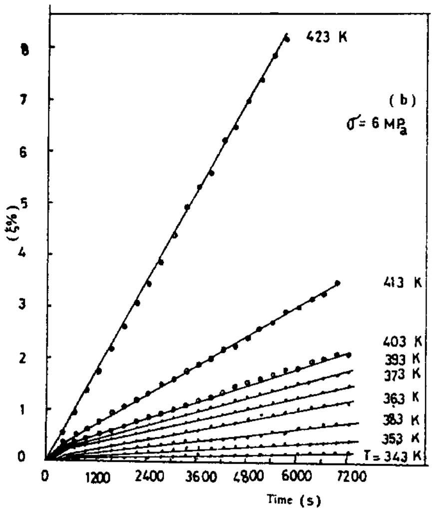
*The rate of "Bi" solubility in "Pb" increase due to the increasing of ageing temperature until 363 K (*the transition temperature*), after 363 K, the β – phase (*Bismuth atoms*) dissolved completely in α - phase *lead atoms*.

Experimental procedure

Pb- 20-wt % Bi alloy was prepared by melting high purity (99.99 %) lead and bismuth in a graphite crucible heated in an ordinary vertical furnace. The ingot was drowning to the form of a rod, then cold hardened by cold drawing to wires of 1-mm diameter and 60 mm lengh. The wires were annealed for one hour at 423 K, then left to cool slowly to room temperature (R.t) with a cooling rate T = 2 x 10^{-2} K/ s^{-1}. To allow the transformations to be nearly complete [15].

The tested Pb-20 wt.% Bi alloy samples subjected to creep deformation under the different stresses 4.5 MPa, 6 MPa,and 7 MPa .The creep curves were conducted at constant temperatures in the range 343 K to 423 K , in steps of 10 K with an error of about ± 1K, passing through the transformation region, using a locally constructed creep machine before and after creep deformation carried out the creep tests. X- ray diffraction patterns were carried out for the samples under investigation, before and after creep deformation.





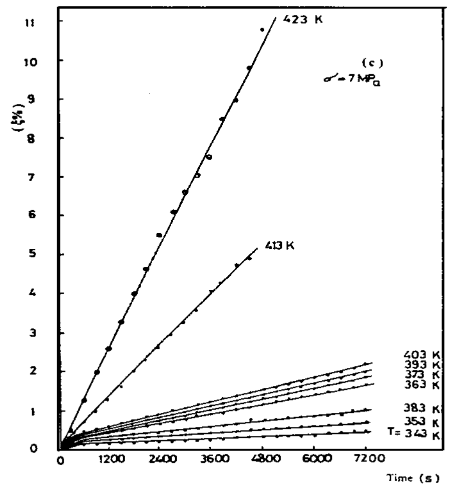


Fig.(1)
Actual creep curves for Pb – 20 wt. % Bi alloy at various temperatures,
a): σ = 4.5 MPa
b): σ = 6.0 MPa
c): σ = 7.0 Mpa.

Experimental results and discussion

Fig. (1) represents the isothermal creep curves for the Pb – 20 wt.% Bi alloy under different applied stresses at different working temperatures. Increasing the ageing temperature and the applied stress led to the observed increase of the steady state creep rate ξ_{st} until and after phase transformation. The regular shift of strain level towards higher values with increasing deformation temperature was interrupted at 363K.

Fig.(2) represents the variations of both transient creep parameters β and n with increasing deformation temperature. The parameter β exhibits values ranging from (0.02 to 0.95) x 10^{-3} and n values ranged from 0.4 to 0.9. Both parameters β and n showed peaks at 363K [16]. This behavior represents a redistribution of the Bi – particles, which were precipitated in the matrix, and some sort of dislocation rearrangement in the dislocation networks during the phase transformation expected at this temperature.

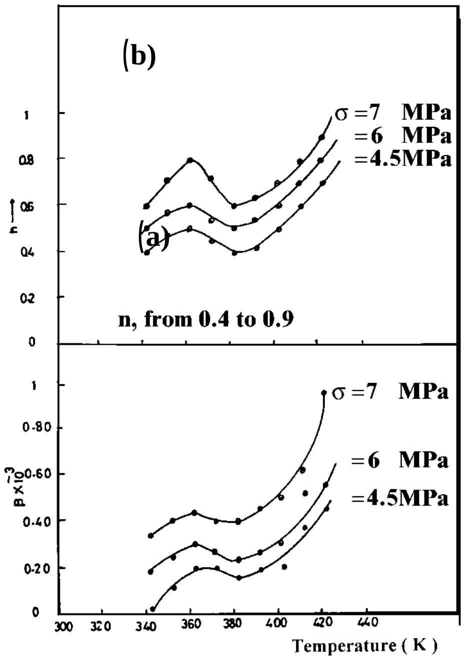


Fig.(2): Temperature dependence of the transient creep parameters n and β.

Fig. (3) illustrates the relation between the steady state creep rate ξ_{st} and deformation temperature under different applied stresses σ. The steady state creep rate ξ_{st} exhibits maximum values at 363 K. This behavior might be due to the segregation of β- phase (Bi atoms) within α-phase (Pb atoms) structure. The rapid increase of ξ_{st} after 363K is thought to be due to the dissolution of the incoherent Bi – particles in the alloy which became more homogenized.

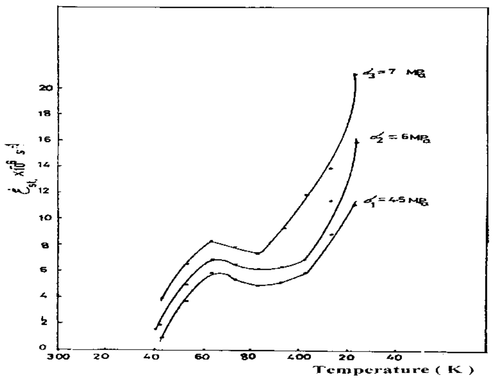


Fig. (3): Steady state strain rate ξ_{st} as a function of temperature.

The strain rate sensitivity parameter m ($m = \partial \ln\sigma / \partial \ln\xi_{st}$) values were derived from the slopes of the straight lines of Fig. (4) which represents the relation between ln σ and ln ξ_{st} for different temperatures. The temperature dependence of the parameter m in Fig.(5) shows a peak at 363 K.

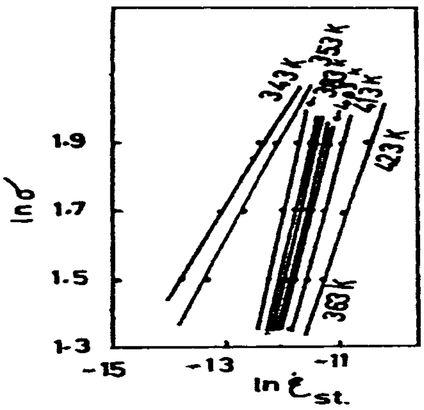


Fig.(4) Relationship between ln ξ_{st} and ln σ at different temperatures.

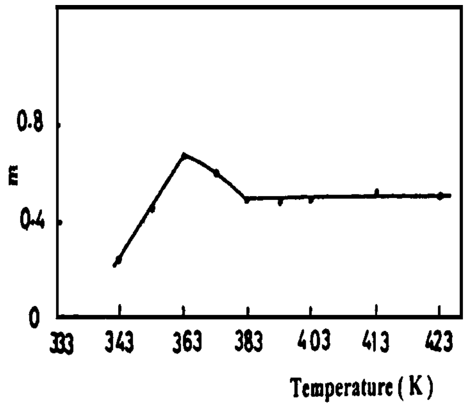


Fig.(5) Strain rate sensitivity "m" versus working temperature.

The correlation between transient and steady state creep stages is represented by the slope γ of the linear relation between ln β and ln ξ_{st}, given in Fig.(6). Near transformation, the ratio γ was found to vary form 67% to 70%. After transformation, γ varied from 65% to 77%. The dependence of the strain rate of the steady state creep ξ_{st} on β seems to be induced by the transformation which enhances the transient and the steady state stages

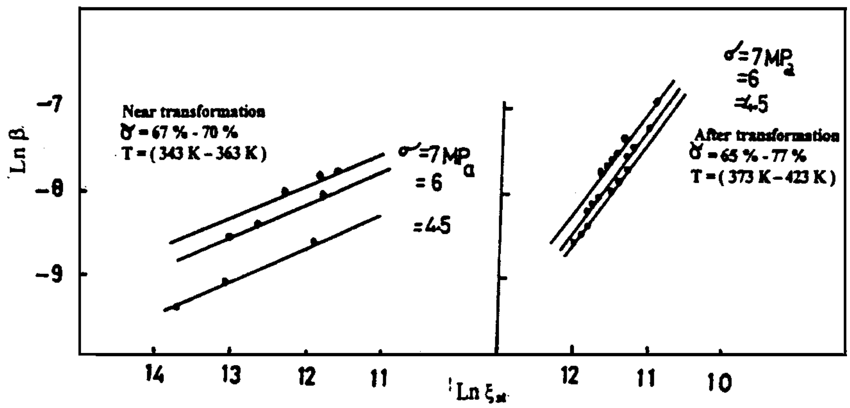


Fig. (6) Relation between ln β and ln ξ_{st} for Pb-20 wt. % Bi alloy at various applied stresses near and after transformation temperature.

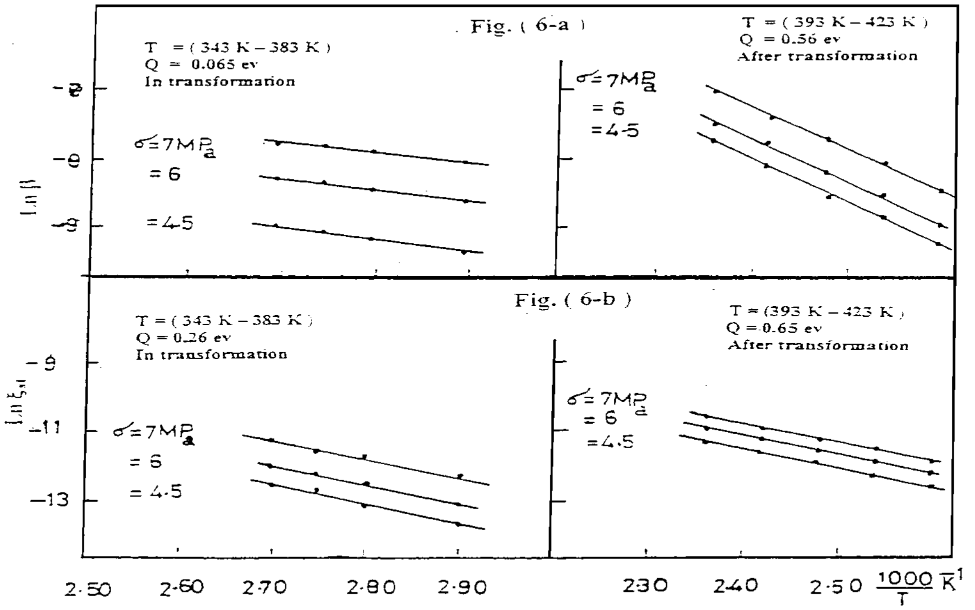


Fig. (7) The effect of creep temperatures on ln β and ln ξ_{st} .

The activation energy Q for both the transient and steady state creep stages were obtained from the slopes of the straight lines of Fig. (7) relating both ln β and lnξ_{st} versus 1/T near and after transformation respectively. Which was characterizing the mechanisms of glide dislocation. The change of Q is happened around 363 K when Bi–particles dissolved. This may be due to the accumulation of the dislocation obstacles produced by the dissolution of solute atoms at the grain boundaries.

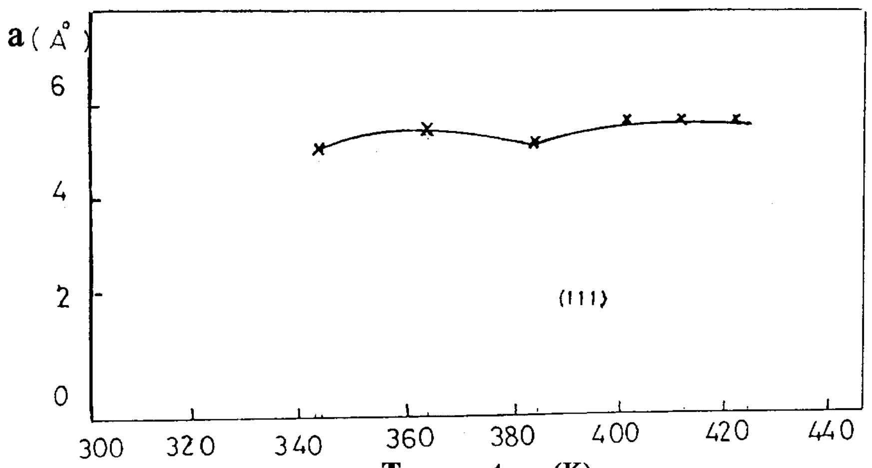


Fig. (8): The effect of creep temperatures on the lattice parameter a.

Fig. (8) shows the relation between the lattice parameter a and the working temperature T, it shows a maximum value at 363 K and minimum value at 383 K. The grain boundary diffusion of Bi in Pb grains is thought to be dominant mechanism producing sliding migration of the dissolved grains into new grains at transformation temperature.

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