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Hot-working characteristics of a Pb-2 wt%Cd alloy during transformation

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Abstract

Stress-strain measurements were carried out on a Pb-2 wt%Cd alloy at different strain rates from 6.4×10^{-4} to $1.0\times10^{-2}\,s^{-1}$ and in the temperature range from 433 to 503 K. The material's dynamic stress–strain response, strain rate, temperature effects and possible deformation mechanisms are discussed. The hot working parameters such as yield stress; ultimate stress, elastic modulus and the total strain were estimated as function of temperature and strain rate to evaluate the structural changes during transformation. Nevertheless, the effect of the transformation on the activation energy and the strain rate sensitivity parameter was studied. Furthermore, the microstructure of the studied samples was investigated below and above the transition temperature (0.65 T_m) using optical microscopy and X-ray analysis.

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1. Introduction

Lead–Cadmium alloys have high potential as structural materials for many technical and industrial applications in particular lead acid batteries [1–9]. Low levels of cadmium addition are known to enhance significantly hardness, wear resistance, mechanical strength, fatigue strength, castability and electrochemical properties during ageing. The additional effect of cadmium is to lower the melting point of Cu, Sn, Pb and Zn-based alloys. Whenever the low melting temperature fusibles containing cadmium are used as heat-sensitive fusible links in fire safety devices or kilns and ovens, they are subjected to repeated thermal cycles, and it becomes necessary to understand how their mechanical properties change with working temperature and applied stress during transformations. In this regard, a number of factors such as grain size and the

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transition of the fully precipitated ($\alpha+\beta$)-phase into the α-phase can affect the kinetics of deformation. Some experimental changes in the mechanical properties of materials were observed while undergoing a phase transformation [10–12].

Hot deformation is one of the most essential phenomena in deformed metals and alloys. It can be explained in terms of the increased and decreased mobility of dislocations [13]. Hardening of polycrystals was found to be due to the activation of Frank–Read dislocation sources and the formation of pile-ups at the grain boundary [14]. Although the creep deformation behaviour and the electrical resistivity measurements of Pb-2 wt%Cd have been discussed [15,16] only little attention has been paid to the study of the effect of temperature and strain rate on the hot-working parameters of this alloy.

In this work, it is aimed to investigate the hot-working parameters such as yield stress σ_y, fracture stress σ_f, ductility ε_{tot}, Young's modulus E for the slowly cooled samples of Pb-2 wt%Cd around the phase transformation.

2. Experimental procedure

The Pb-2 wt%Cd alloys were prepared from high-purity Pb and Cd (99.99%). The mixture was melted in a Pyrex tube in the vicinity of a fluxing material to prevent sample oxidation in air. The ingot was placed in a tube furnace at 350 °C for about 25 min while shaking the tube to achieve homogenization. The alloy was allowed to cool and solidify. After solidification the tube was broken and the alloy was washed by pure carbon tetrachloride several times. The ingot was annealed at 423 K for 24 h to ensure its homogeneity and slowly cooled to room temperature at a cooling rate of $2\times10^{-2}\,\mathrm{K s^{-1}}$. Then, the ingot was cold rolled into wires of diameter 8×10^{-4} m and length of 5×10^{-2} m suitable for the tensile tests. The wire samples were annealed at 423 K for 2 h and slowly cooled to room temperature at the same cooling rate previously mentioned to eliminate the cold work introduced during the rolling process. The tensile tests were carried out after one hour using an Instron machine with experimental accuracy of $\pm3\%$, in the temperature range 433–503 K in steps of 10 K using a type-k thermocouple and temperature controller with accuracy of ±1 K and at initial strain rates in the range 6.4×10^{-4} to $1.0\times10^{-2}\,\mathrm{s^{-1}}$. The grains were obtained using a Nikon optical microscope (OM). The microstructure was obtained using X-ray diffraction (XRD) with a Philips (1930) diffractometer.

3. Results and discussion

3.1. Stress-strain characteristics

Fig. 1a shows a series of typical true stress–true strain curves of the Pb-2 wt%Cd alloy at a strain rate of $6\times10^{-3}\,\mathrm{s^{-1}}$ at temperatures ranging from 433–503 K. Whereas Fig. 1b shows the true stress–true strain relation in the same investigated Pb-2 wt%Cd alloy at constant temperature (473 K) and different strain rates in the range from 6.4×10^{-4} to $1.0\times10^{-2}\,\mathrm{s^{-1}}$. It can be seen from figures that the curves exhibit flow hardening just after yielding for samples deformed at $T<473$ K and strain rate of $1.0\times10^{-2}\,\mathrm{s^{-1}}$. On the other hand, in case of alloys deformed at $T\geqslant473$ K or strain rate $\dot{\varepsilon}\leqslant6\times10^{-3}\,\mathrm{s^{-1}}$, the flow curves exhibit almost a steady-state flow after an immediate stage of hardening. However, oscillating flow curves between flow hardening and steady-state behaviour at 483 K suggest a rapid transition from the α- and β- phase to the actual equilibrium composition consisting of a α phase-solid solution. This transition point is in good agreement with that obtained previously in creep deformation [15] and electrical resistivity measurements [16] on the same alloy.

3.2. Temperature and strain rate dependence of the hot working parameters

The temperature and strain rate dependence of the yield stress σ_y, the ultimate stress σ_u and the total strain ε_{tot} are shown in Fig. 2a–c. It is clear from the figures that these parameters decrease with increasing working temperature and/or decreasing strain rate and exhibit a transition point at 483 K. The decrease in the hot-working