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A study of annealing stages in commercial pure Cu using mechanical measurements and positron annihilation lifetime technique

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ABSTRACT

Mechanical property measurements, positron annihilation lifetime (PAL) measurements and metallographic observations, have been performed to study the isochronal annealing of commercial pure Cu in the temperature range from 25 up to 850 °C. A positive correlation has been found between positron lifetime (τ) and both the tensile strain ($\Delta L/L_0$) and Vicker's microhardness (H_v). This correlation shows the presence of three annealing stages in commercial pure Cu which are attributed to recovery, recrystallization, and grain growth. These different stages were studied by both pure tensile and combined torsion–tension deformation for samples pre-annealed at the different annealing stages. Plastic instability behavior is observed in the case of combined torsion–tension deformation. It is observed that the onset and disappearance of this instability depend on some parameters such as mode of deformation, applied axial tensile stress and pre-annealing temperature.

The activation energy is found to be 0.5 eV for the recovery stage which is attributed to the energy for dislocation annihilation by glide or cross-slip. The recrystallization stage is a multi-energy stage (1.35, 1.6, and 1.71 eV) which is attributed to lattice diffusion or boundary diffusion.

1. Introduction

The plastic behavior of alloys has been the subject of a number of investigations during the past decade [1–3]. Dislocation arrangements have been studied [4,5] in polycrystalline alloys deformed by torsion. It is well known that in the course of twisting polycrystalline metal wires, an axial elongation is produced [4]. Such an elongation is enhanced even by small axial tensile stresses and becomes homogeneous and easily measurable. Variation of the produced elongation occurs mainly when the mode of deformation varies. Heavily deformed metals and alloys are susceptible to plastic instability, i.e. strain localization mainly occurs when the mode of deformation changes [3,6].

The positron is known to be a probe of high sensitivity to local regions of low atomic density in metals and alloys [7]. Positron annihilation spectroscopy (PAS) in particular positron annihilation lifetime (PAL) technique has an advantage in probing dislocations, vacancies, and vacancy clusters [8]. Some investigations have been performed for studying commercial pure Cu and Cu alloys using PAS [9–12].

To throw more light on the characteristics of instability, this work is done to study the hardening mechanisms controlling the tensile strain associated with pure tension as well as combined torsion–tension deformation in copper. Furthermore, a correlation is undertaken between the microstructure defects given by PAL and the characterization of material through the measurements of Vicker's microhardness and tensile strength. The study is of technological interest as the copper is important in the industrial engineering.

2. Experimental

2.1. Material used and specimen preparation

The material used in the present investigation is a commercial pure copper (99.88%) supplied by Helwan Company for non-ferrous metals in the form of a block 5 cm × 10 cm × 100 cm. Pieces of the material are shaped through extrusion by wire drawing at the room temperature. The chemical compositions of the material are given in Table 1.

Surface cleaning with benzene has been carried out on each specimen to remove any dust or grease. The test specimens are, then carefully chosen after the microscopic examination of the surface. The specimens which show any notches or scratches are excluded since it might give error results.

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2.2. Tensile measurements

Kinston 5500R universal testing machine is used for determining the stress–strain of the samples according to ASTM D638 (2000). In our measurements, the extension rate used is 12 mm/min. The accuracy of elongation measurements amounts to about ±1%. The ultimate tensile stress (UTS) is measured at the room temperature from the load-elongation experiments that are made for the samples using the tensile testing machine. Isochronal annealing experiments for 10, 20, 30 min are carried out. The samples are given pulse annealing at a temperature from 25 up to 850 °C in steps of 25 °C.

2.3. Combined torsion–tension deformation

Wires of 0.5 mm diameter were annealed for one hour at different temperatures (25, 150, 250, 350, 450, 650 and 850 °C), then subjected to uniform twisting in the twisting machine described elsewhere [5]. The degree of torsion deformation was measured [3] by the dimensionless quantity ND/L_0 where N being the number of twist turns, D is the wire diameter (0.5 mm), and L_0 is the original wire length (50 mm). During twisting the tested wire, was axially loaded by tensile stress (not more than one-third of the yield point) to prevent the bending (buckling) of the sample [13]. The variation in length accompanied by the torsion–tension deformation was measured by a travelling microscope with accuracy up to 10^{-2} mm.

Table 1
The chemical compositions for commercial pure Cu.

Impurity	S	Si	Ni	Pb	Fe	Mg	Ca	O_2
Wt%	0.002	0.001	0.10	0.001	0.10	0.0005	0.0001	400 ppm

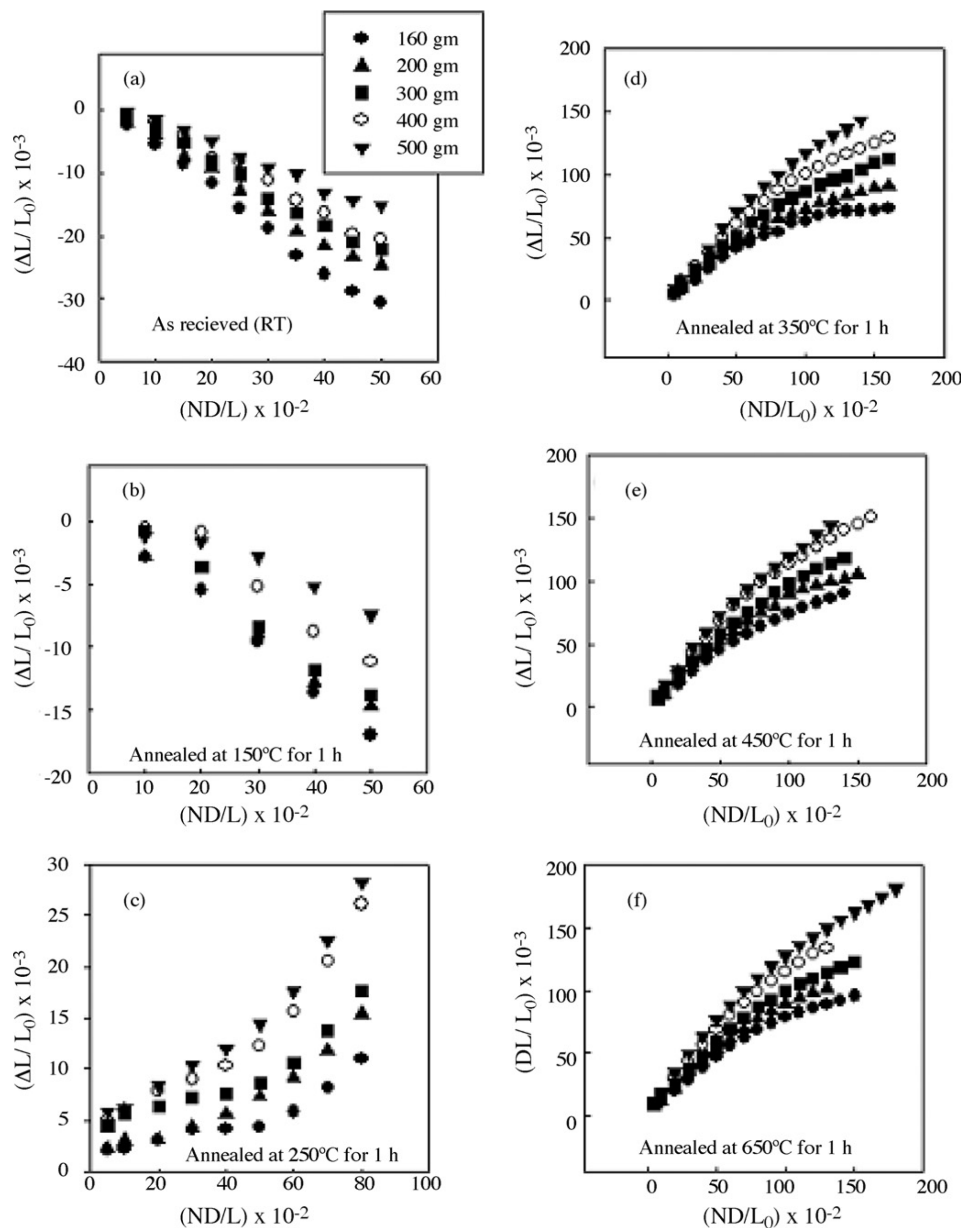

Fig. 1. (a–f) The variation of tensile strain $\Delta L/L_0$, produced by torsional deformation (ND/L) for wires pre-annealed at RT, 150, 250, 350, 450, and 650 °C.