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Positron Annihilation Study of Deformation in a Two-phase (α+β) Cu–Zn Alloy

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Abstract

Positron lifetimes have been measured as a function of the degree of deformation ϵ in a two-phase (α+β) Cu–Zn alloy. In this alloy the increase of the mean positron lifetime τ_m with ϵ is slower and the saturation effect occurs at a larger deformation than that in most simple metals and alloys. With increasing ϵ the positron lifetime parameters τ_1 I_1 and I_2 exhibit a rise or fall near $\epsilon \approx 4\%$ and 35%, and they change slowly for $4\% < \epsilon < 35\%$. These results are explained by the special structure of the α and β phases and the particular deformation mechanism in this alloy.

1. Introduction

Positron annihilation lifetime spectroscopy (PALS) has been used successfully to investigate defects in many metals and alloys (Hautojarvi 1979; Brandt and Dupasquier 1983). Perhaps due to complexity, the earlier positron annihilation studies on deformation defects were limited mainly to simple metals and alloys and did not look at complex polycrystalline materials. During the last decade positron annihilation studies on defects of more complex materials, such as complex alloys and ceramics, have been undertaken. In the present work we have studied deformation defects in a two-phase co-existing Cu–Zn alloy by PALS.

Although Cu–Zn as a typical binary alloy has been investigated in detail using positron annihilation methods, most works have investigated vacancy formation energy (Schultz *et al.* 1978; Dlubek and Brummer 1979; Kim and Buyers 1980; MacKenzie *et al.* 1980; Chabik and Rozenfield 1981), the determination of the Fermi momentum and Fermi surface (Morinaga 1972; Triftsauser and Stewart 1971; Williams 1968; Becker *et al.* 1971; Berko and Mader 1975; Haghgooie *et al.* 1979) or the order–disorder transition (Schultz and Mackenzie 1982).

These studies have tended to analyse the single-phase (α-, β-, γ-) Cu–Zn alloys, whilst study of the mixed-phase (α+β, α+β, etc.) Cu–Zn alloy with its unusual structure and properties has been rare. The object of the present work is to study deformation defects in the complex α+β mixed-phase Cu–Zn alloy and to verify, at the same time, the sensitivity of positron annihilation to structure in such complex materials. Some interesting results are obtained and discussed.

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2. Experiments

The experimental material is a two-phase ($\alpha+\beta$) alloy of Cu–38 wt% Zn. A casting of Cu–Zn alloy was forged, then extruded into bar material. Six cylinders of 10 mm diameter and 30 mm length, cut from the same bar material, were annealed firstly at 600°C for 4 h and then deformed in compression with 0, 4, 14, 27, 38, 47% thickness reduction at room temperature. Two sheets of 1 mm thickness as experimental samples were cut from the middle of each cylinder. The variations of structure and defects in the deformed samples were probed by PALS, SEM and TEM.

The positron lifetime spectra for all samples were collected at room temperature using a fast–fast coincidence spectrometer with a time resolution (FWHM) of 260 ps. A sample of ^{22}Na of about 10 μCi was used as the positron source. A total of 1×10^6 counts were collected for every spectrum. After subtracting the source and background contributions all lifetime spectra were fitted with two exponential components (fitting variance of 0·90–1·14) using the program POSITRONFIT-EXTENDED. (The spectra were also fitted with three components, but the fitting variances are much more than that in two-component fitting and so the results of two-component fitting are adopted here.) The lifetimes τ_1, τ_2 and their relative intensitives I_1, I_2 were obtained. The mean lifetime τ_m was found from

$$\tau_m = I_1\,\tau_1 + I_2\,\tau_2\,. \tag{1}$$

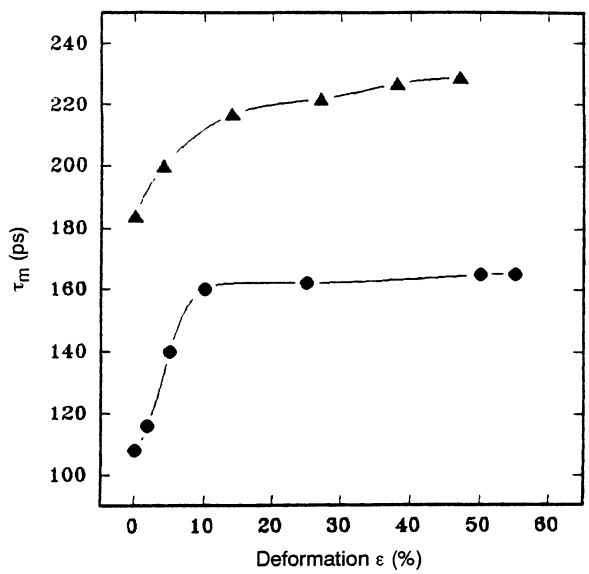

Fig. 1. Mean positron lifetime τ_m as a function of the deformation ϵ in a two-phase ($\alpha+\beta$) Cu–Zn alloy (triangles) and in α–Fe (circles) (Berko and Mader 1975). The standard deviation of τ_m is ±2 ps.

3. Results and Discussion

Values of τ_m, τ_1, I_1, τ_2 and I_2 as a function of deformation degree ϵ are shown in Figs 1, 2 and 3. It is known that positrons can be trapped by many kinds of defects, such as vacancy, dislocation, void, grain boundary, phase interface, and all may occur in our experimental samples. Many studies (Vehanen and Rytsola 1983; Tang *et al.* 1993*a*, 1993*b*, 1993*c*) have shown that when positrons annihilate at the same time from many different states, if the number of the fitted component is less than that of the positron states in the samples, one component decomposed from a lifetime spectrum is often the weighted average value of some actual state lifetimes coming close to each other, and τ_m defined in (1) is the weighted average value of various actual state lifetimes. Considering that the bulk lifetime is 122 ps for Cu and 160 ps for Zn, that the positron lifetime in vacancies is 182 ps for Cu and 216 ps for Zn (Mackenzie 1983), and that the positron lifetme in a dislocation is close to that in a vacancy, the present observed lifetime τ_1 of 148–207 ps may arise from positrons annihilating in the bulk, vacancies and dislocations. It is evident that the observed τ_2 component of 391–565 ps can be associated with positrons annihilating in voids and at grain boundaries and phase interfaces. The values of I_1 and I_2, which are relative intensities of positrons annihilating in smaller size defects such as dislocations and vacancies and in bigger size defects such as voids, respectively, reflect the relative concentrations of smaller size and bigger size defects. Also the value of τ_m reflects the variation of total defects.

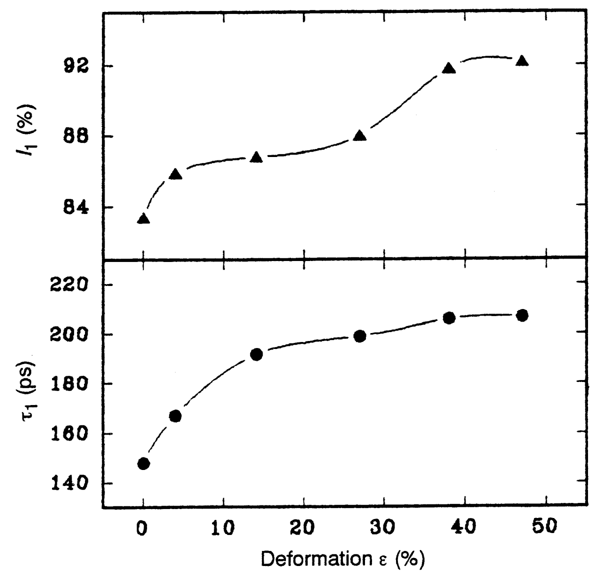

Fig. 2. Positron lifetme τ_1 and its relative intensity I_1 as a function of deformation ϵ in a two-phase (α+β) Cu–Zn alloy. The standard deviation of τ_1 is ± 2 ps.

It is seen from Fig. 1 that τ_m increases with ϵ, but the increase is faster for a lower deformation ($\epsilon < 14\%$) and become slow above $\epsilon = 14\%$. This deformation dependence of τ_m, roughly speaking, is in agreement with that observed in most metals and alloys. This tendency of τ_m indicates that the total concentration of defects in the samples is increased. However, in terms of the detailed variation of τ_m, the present result is different from that observed in simple metals and alloys. It is known (Hautojarvi 1979) that in simple metals and alloys, with increasing deformation ϵ, the mean positron lifetime τ_m and the Doppler broadening parameters H or S increase rapidly under low deformation, change very slowly in the deformation range 5–10%, and reach saturation above 10–20%; for example, the variation of τ_m in the deformed α–Fe (Brabander *et al.* 1982) (see Fig. 1).

It is also seen from Fig. 1 that under lower deformation the rise of τ_m with increasing deformation is slower in our samples than in deformed α–Fe and the saturation effect occurs at larger deformation in our samples than in α–Fe. These differences may result from the different structures and deformation mechanisms of materials. Because τ_m reflects only the total variation of the defects, the detailed variation of these defects is difficult to obtain. These variations are discussed further below.

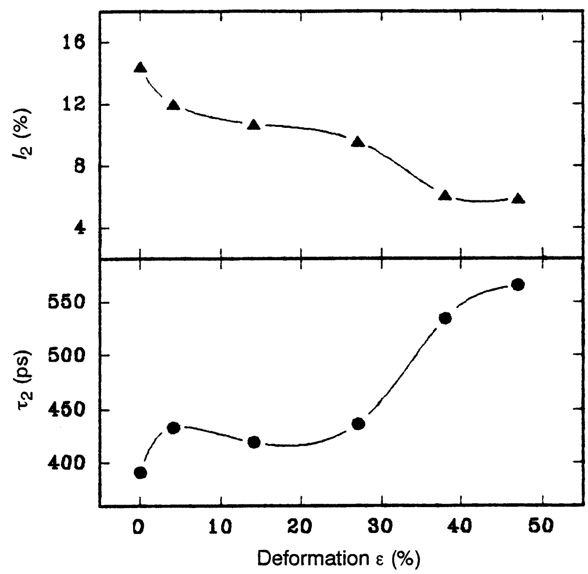

Fig. 3. Positron lifetime τ_2 and its relative intensity I_2 as a function of deformation ϵ in a two-phase (α+β) Cu–Zn alloy. The standard deviation of τ_2 is ± 4 ps.

For the undeformed sample, when we consider that prior to deformation the alloy material was annealed at 600°C, a value of $\tau_1 = 148$ ps lying between the bulk lifetimes of Cu (122 ps) and Zn (160 ps) can be regarded as the weighted value of the bulk lifetimes in two phases, while the value $\tau_2 = 391$ ps arises mainly from positrons annihilating at grain boundaries and phase interfaces.

To understand the variations of τ_1, τ_2, I_1 and I_2 in the deformed samples, it is worth recalling earlier knowlege on deformation in the (α+β) phase Cu–Zn alloy. Hedworth and Pollard (1971) found that in the (α+β) phase Cu–Zn alloy the fault energy of the α phase having fcc structure is lower than that of the β phase having bcc structure. This difference may cause different deformation effects in two phases. Hedworth and Pollard (1971) showed that the deformation undergoes three stages: the first is where the elastic deformation occurs in both α and β phases at the same time; with increasing compression the deformation enters the second stage in which the α-phase enters the plastic deformation while deformation in the β phase is still elastic; and when large enough compression is applied the third stage starts and plastic deformation also occurs in the β phase.

Because the deformation is elastic in the first stage, the deformation effect is difficult to retain in the samples. Thus the present positron lifetime parameters include only the deformation effect during the second and third stages. It is seen from Figs 2 and 3 that the parameters exhibit variations near both $\epsilon \approx 4\%$ and 35%. These variations may be the start of the second and third deformation stage. As a result the variation of the parameters in the deformation samples can be explained as follows.

The variation of τ_1 with ϵ is similar to that of τ_m (see Figs 1 and 2). This similarity indicates that τ_1 is the main contributor to τ_m and the variation of the main defect in the material can be revealed from the variation of τ_1. Clearly, the interesting variations of τ_m and τ_1 result from the specific structure and deformation mechanism of this alloy.

The rapid increase in τ_1 and I_1 near $\epsilon \approx 4\%$ (Fig. 2) can be attributed to the rapid production of dislocations and vacancies in the α phase early in the second deformation stage. The increase of τ_1 and I_1 slows above $\epsilon \approx 4\%$ and becomes quite slow above $\epsilon = 10\%$, indicating that the increase of the dislocation and vacancy concentration in the α phase has slowed. Near $\epsilon \approx 35\%$ the rise in τ_1 and I_1 are due to the dislocations and vacancies produced in the β phase early in the third deformation stage.

It is seen from Fig. 3 that the variation of τ_2 exhibits a more evident rise near $\epsilon \approx 4\%$ and 35%, but for $4\% < \epsilon < 30\%$ τ_2 remains basically constant. These variations are not observed in most simple metals and alloys. Evidently these variations are associated with the specific structure and deformation mechanism of this alloy. Our observations for the deformed samples using SEM and TEM show that:

(a) Voids form mainly at the grain boundaries and the interfaces. With increasing deformation the voids form firstly at the grain boundaries in the α phase, then at the interfaces between the α and β phase, and lastly at the grain boundaries in the β phase.

(b) The size of voids formed at the grain boundaries in the α phase is not changed with deformation.

(c) A large number of deformation twins occur near the grain boundaries in the α phase.

Considering these cases the smaller rise in τ_2 at $\epsilon \approx 4\%$ may result from the initial formation of voids, the flat part of the τ_2 curve for $4\% < \epsilon < 30\%$ is probably associated with positrons annihilating in voids formed at the grain boundaries of the α phase, and the larger rise in τ_2 near $\epsilon \approx 35\%$ may be contributed by larger voids formed at the interface between the α and β phase.

As mentioned above, variations of I_1 and I_2 reflect the variation in concentration of smaller size defects, such as dislocations and vacancies, and the bigger size defects such as voids. The fact that I_2 is much less than I_1 indicates that the concentration of voids is much lower than that of dislocations and vacancies. The decrease in I_2 with increasing ϵ is a relative change, it indicates only that the increase of voids is slower than that for dislocations and vacancies. Evidently, these characteristics of I_2 can be attributed to voids forming mainly at grain boundaries and phase interface.

4. Conclusion

PALS can be used to probe deformation defects in complex alloys. The variations of the positron lifetime parameters with deformation in the $(\alpha+\beta)$ Cu–Zn alloy are different from those in most simple metals and alloys. Here the increase of τ_m with ϵ is slower and the saturation effect occurs at larger deformation than in most simple metals and alloys. The τ_1 component can be regarded as the weighted value of the positron lifetimes for bulk, vacancies and dislocations, and the τ_2 component can be associated with positron annihilation in voids and at grain boundaries and phase interfaces. With increasing ϵ, the evident rise or fall of τ_1, I_1, τ_2 and I_2 near $\epsilon \approx 4\%$ and 35% results from the special phase structure and deformation mechanism of this alloy.

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