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1963

SovietRxiv

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PHYSICAL CHEMISTRY

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ON THE COMBINED ACTION OF MERCURY AND RADIOACTIVE RADIATION ON THE MECHANICAL PROPERTIES OF ZINC SINGLE CRYSTALS

(Presented by Academician P. A. Rebinder, 12 XII 1962)

Earlier we showed that β-irradiation, together with a surface-active mercury coating, causes a considerable enhancement of the adsorption effect of lowering the strength of zinc single crystals. In individual cases the strength proved to be reduced tenfold in comparison with crystals likewise amalgamated but not subjected to irradiation. At the same time, not too prolonged irradiation (no more than 50 h) may lead, conversely, to a certain increase in strength and a noticeable increase in plastic deformation, if the tests of the specimens are carried out in the absence of the radiation source $^{(1-3)}$.

In the present work we studied the influence of irradiation by various types of radiation on amalgamated zinc single crystals at longer exposures. Laboratory-type β-, α-, and γ-emitters were used, with the corresponding radioactive isotopes P^{32}, Pu^{239}, and Co^{60}. The β-emitter, with an initial activity of 200 μ Cu, was made in the form of two cassettes 70 mm long and 12 mm wide, having active spots in the form of a deposit of $Na_2HP^*O_4$ salt and mounted in a special holder. The α-emitter had the form of a vertically arranged hollow cylinder, on the inner side of which seven small cassettes, shaped like little boats of stainless steel, were mounted. Each cassette contained 4.28 mg of Pu with a specific activity of $1.43 \cdot 10^8$ decays/min per 1 mg. As the γ-emitter a stationary cobalt source with an activity of $4 \cdot 10^4$ g-eq radium was used. All the emitters ensured uniform, all-sided irradiation of the specimens at 20°. In the case of α- and β-irradiation the specimens were located at a distance of 4–5 mm from the active layer.

Specimens of single-crystal zinc, 10 mm long and approximately 1 mm in diameter, were grown by the zone-melting method. As in our previous work, after etching with a 20% HNO_3 solution, mercury was deposited on the surface of the specimens by a contact method from a nitric-acid solution. However, in view of the duration of the experiment, the amount of mercury deposited was taken not as ~ 1 wt.%, as before, but approximately 3 wt.%. A certain excess of mercury guaranteed the presence of a liquid metallic phase throughout the irradiation

Fig. 1.

Figure 1: Fig. 1.

Fig. 2.

Figure 2: Fig. 2.

process. Tests were carried out on a Polanyi apparatus (tension at a constant deformation rate of $\sim 10\%$ $\min^{-1}$ at 20° and at −196°; during deformation the specimens were not irradiated).

In Fig. 1 are presented tensile diagrams of amalgamated zinc single crystals with $\chi_0 \simeq 38°$, irradiated before deformation for 1550 h in β- and α-emitters, and of specimens not subjected to irradiation but held in the amalgamated state for the same time as the irradiated ones. Fig. 2 shows analogous tensile diagrams of crystals with $\chi_0 \simeq 35°$, irradiated after deposition of mercury in the γ-emitter for 1450 h, taken also at −196° and +20°. As is seen from these graphs, tests at both normal and low temperatu-

···which cause hardening of the mercury melt, show a decrease in the strength and plasticity of the specimens. We have previously established (^{1}) that, after brief β-irradiation, zinc crystals containing a film of mercury, when stretched outside the field of the emitter at normal and low temperatures, exhibit a marked increase in plasticity, as well as some increase in strength, especially after freezing the surface-active melt at −196°. As can be seen from the tensile diagrams shown in Figs. 1 and 2, irradiation for 1450–1550 h produces an inversion of this effect: instead of an increase in plasticity and a certain rise in strength, there is considerable weakening and embrittlement.

Fig. 1. Effect of preliminary β- (2) and α- (1) irradiation for 1550 h on the tensile diagram of amalgamated zinc single crystals, $\chi_0 \simeq 38°$, and their deformation without irradiation (3) at −196° (solid curves) and +20° (dashed curves).

Fig. 2. Effect of preliminary γ-irradiation (1) for 1450 h on the tensile diagram of amalgamated zinc single crystals, $\chi_0 \simeq 35°$, and their deformation without irradiation (2) at −196° (solid curves) and +20° (dashed lines).

Figure 3 presents the dependence of the effect of the change in strength,

$$\frac{P^0 - P}{P} \cdot 100\%,$$

as a result of irradiation of amalgamated zinc single crystals, on the exposure time in the field of a β-emitter with an initial activity of $200\,\mu$ Cu. Figure 4 gives a plot of the influence of β-irradiation on the plasticity of amalgamated zinc single crystals. In these plots, P^0 and ε^0 are, respectively, the strength

Fig. 3

Figure 3: Fig. 3

Fig. 4

Figure 4: Fig. 4

and relative elongation of the irradiated specimens; P and ε are those of the nonirradiated specimens; and τ is the exposure time under irradiation before testing, in hours. To construct the plots, the results of testing specimens at +20° and −196° were used (without irradiation during the deformation process).

As can be seen from Fig. 3, the maximum strengthening, +35%, in tests of specimens at −196° corresponds to an exposure of 16-18 h. At longer exposures, corresponding to approximately 1000 h, there arises···

shows, conversely, the effect of considerable weakening—by 50% in tests at low temperatures and by 75-80% at 20°. The relative elongation of the irradiated specimens changes in an analogous manner: at first there is significant plasticization—by 300%, corresponding to an exposure of 25-26 h; then embrittlement sets in.

The increase in strength at comparatively small exposures is associated with the production of radiation defectiveness and, as a result, the intensification of the diffusive penetration of mercury into zinc (alloying). The alloying process also takes place at longer exposures in the radiation field, but it no longer plays any appreciable role. In the region of values of τ greater than 100 h, the determining process becomes the coalescence of point defects and the nucleation of new internal separation surfaces filled with mercury, leading to a decrease in the strength of the crystals during their deformation (^{1}).

Fig. 3. Dependence of the effect of the change in strength
$\frac{P_0 - P}{P} \cdot 100\%$ of amalgamated zinc single crystals
$\chi_0 \simeq 20 \div 45°$ as a result of β-irradiation on the exposure time in the radiation field. Tensile testing at a constant strain rate ~ 10 min^{-1} was carried out at +20° (1) and −196° (2) without irradiation during deformation.

Fig. 4. Dependence of the effect of the change in plasticity, according to the limiting elongation
$\frac{\varepsilon_0 - \varepsilon}{\varepsilon} \cdot 100\%$, of amalgamated zinc single crystals
$\chi_0 \div 20 : 45°$ as a result of β-irradiation on the exposure time in the radiation field. Tensile testing at a constant strain rate $\sim 10\%$ min^{-1} was carried out at +20° (1) and −196° (2) without irradiation during deformation.

Plasticization of preliminarily irradiated specimens, expressed in an increase of the plastic deformation preceding fracture, is apparently explained by the uniformity of distribution of the surface-active melt along the existing defects of the structure during irradiation. Under these conditions, plastic shifts in the early stages of deformation do not lead to sharply pronounced deformation microinhomogeneities and to the occurrence of local stresses exceeding the critical level.

The exposure at which inversion of the effects of plasticization and strengthening occurs is 3–4 days. At a source activity of 200 μCi, this exposure corresponds to a high density of induced radiation defectiveness. In this connection, the process of coalescence of defects develops vigorously, leading to the formation of ultramicrocracks, dis-

located mainly along block boundaries, and to a sharp decrease in the plasticity and strength of the crystals. In the absence of irradiation, such ultramicrocracks arise only in the course of plastic deformation at a definite and comparatively high value of the shear and normal stresses. It should be noted that, in the absence of a surface-active medium (mercury), such cracks do not reduce the strength of zinc single crystals, since, with respect to the acting normal stresses, their size is far from critical. But in the presence of mercury, and as a result of the strong reduction of the surface energy on the walls of these embryonic cracks caused by it, even at small stresses their dimensions become very close to critical, and premature brittle fracture of the crystal occurs (⁀5).

In the case of α-irradiation, the greatest change in the structure of the metal occurs in the surface layer, since α-particles have an insignificant penetrating power (not more than 13 μ in the metal). The presence of a weakening effect in this case as well (Fig. 1) indicates that, during α-irradiation, the role of surface structural defects filled with mercury and serving as crack nuclei, leading to brittle fracture during deformation, increases. Numerous experiments show that, under the influence of α-irradiation, the effect of the weakening action of molten mercury on zinc single crystals, at the same integral irradiation dose, appears even earlier than under β- and γ-irradiation. This is explained by the fact that α-irradiation, unlike β- and γ-irradiation, can lead not only to isolated displacements of Frenkel-pair type (interstitial atom—vacancy), but also cause local disorder in the crystal lattice, for example of the kind discussed in (⁀4), increasing the density of dislocations at the surface, which in turn, in the presence of a surface-active melt, facilitates the nucleation of dangerous surface structural defects.

The authors express their gratitude to I. M. Kuleshov, head of the Laboratory of Radioactive Isotopes of the Radiochemistry Department of the Institute of Physical Chemistry, Academy of Sciences of the USSR, for providing the opportunity to carry out the experiments and for valuable advice.

Institute of Physical Chemistry
Academy of Sciences of the USSR

Received
3 XII 1962

CITED LITERATURE

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