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KINETICS EXOELECTRON EMISSION PHENOMENA: CONFIRMED MECHANISM OF VACANCY DIFFUSION THROUGH DISLOCATION

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On the basis on the data obtained during experiments regarding the kinetics of exoelectron emission phenomenon in deformed metal, a hypothesis concerning the dislocation mechanism of vacancies transport was confirmed.

1. Introduction

The nature and character of the exoelectron emission (EEE) phenomenon accompanying a plastic deformation of thermally or mechanically prepared metals showed distinct relations between the EEE phenomenon and the defects of a crystalline structure produced during processing. On the basic of the result obtained for the Ni and stainless steels [1, 2] has been concluded that the EEE intensity accompanying an uniaxial deformation appears at the yield strain ε_0 on the stress-strain curve, and that the sharp "destruction" emission peak is associated with the sample failure strain ε_f .

Long before Von Voss and Brotzen [3] as well as Pimbley and Francis [4] connected exoelectron emission with the creation of emission centres as a result of voids diffusion to the surface. Von Voss and Brotzen [3] connected the phenomenon of exoelectron emission with the presence of voids in crystalline lattice on the surface, and with their dissociation. Later papers of Sujak et al. [5-8] confirm this idea completing it only with considerable effects of intermediate layer between the surface oxide layer and metallic core upon the exoelectron emission kinetics and cracking of oxide layer connected with the extension test. On the basic of investigation of the emission intensity dependence upon time, during and after extension test, it has been determined that the emission comes from centres generated in the undersurface to the surface [2]. The investigation of Sujak et al. [9-11], Hanke [12] and Bohun [13] allow to decide that the emitted charge bariers are electrons, and to connect their emission with the presence of electron traps. It was necessary to explain the mechanism of transport of the point defects towards the emitting surface. The measurements of the effect of stainless steel deformation rate kinetics of photostimulated exoemission at low temperatures [14] with the determined concentration of the point defects and dislocations, by means of a X-ray method [15] as well as later results [1, 2] confirm the assumption of the diffusive mechanism of transport of the point defects (vacancies-emission centres) from the bulk of the specimen towards its surface. This hypothesis needs the widely confirmation. It was found that the exoelectron emission intensity accompanying an uniaxial deformation appears at the yield strain ε_0 on the stress-strain curve. Simultaneously, after exceeding the yield point the plastic strain resulted from the motion and generation of dislocations appears. As it was seen in [2] both the failure deformation (ε_f) and the intensity of exoelectron emission for ε_f can be described by similar functions the density of dislocations generated during deformation. It was the first considerably circumumstance, which was to prove this hypothesis. In the present work, we intend to confirm the assumtion relating the dislocation mechanism of vacancy transport towards the emitting surface, through the manifestation increase and motion of dislocations (Lüders-Hartmann bands).

2. Experimental details

The observation and recording the Lüders-Hartmann bands and decay process of electric field, and the measurements of exoelectron emission above the yield point were performed for aluminium sheet covered with the polar liquid crystal and illuminated monochromatic nonopolarized as well as polarized light. In particular:

(1) microscopic observation and recording of the Lüders-Hartmann bands were with the polar liquid crystal on the sample surface, but without polarized light;

(2) recording the EEE intensity was performed with sample surface without a polar liquid crystal;

(3) the decay process of electric field were performed with the polar liquid crystal on the sample surface, and the observations were performed in the polarized light.

The exoelectron emission intensity was measured by means of a point counter of air-flow type containing a saturated vapour of ethyl alcohol [2]. EEE measurements were performed both with optical stimulation by laser diode radiation and without any stimulation. The specimen was deformed at a deformation rate from 0.306×10 ms^{-1} to 5.27×10 ms^{-1}. Measurements of the EEE intensity with time deformation for given speed of tension were carried out at room temperature. Each measuring point was the average of the 30 independent measurements under identical conditions.

3. Results and discussion

An analysis of the relationships between intensity of exoelectron emission with time and simultaneously strain with stress for the same samples allows us to assume that the emission intensity accompanying uniaxial tension (from $\varepsilon = 0$ to the strain at the sample failure ε_f) depends on the actual value of a specimen strain. This can be seen

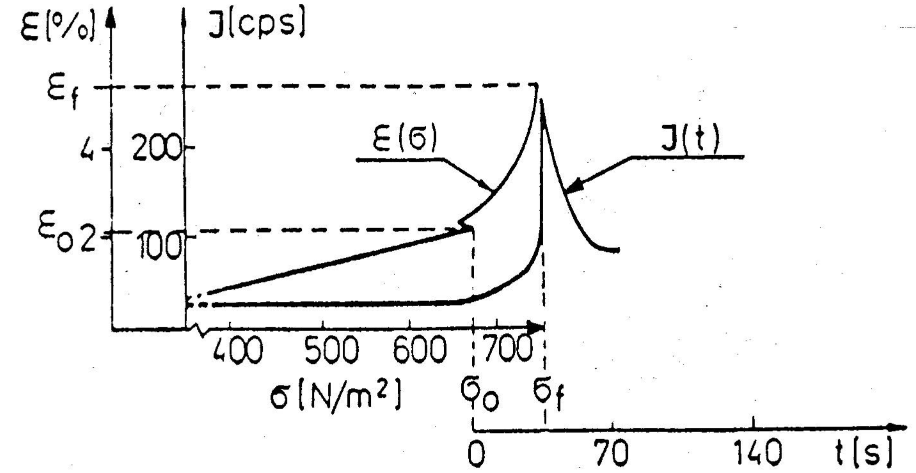

Fig. 1. True strain ε versus tensile stress σ and intensity of exoelectron emission versus time $N(t)$

in Figure 1 that the EEE curve for the initial state of an as-made sample is compared with stress (σ) - strain (ε) curve. From this comparison it has been concluded that the EEE intensity $I(t)$ accompanying an uniaxial deformation appears at the yield strain ε_0 on the stress-strain curve, and that the sharp "distribution" emission peak is associated with the sample failure strain ε_f . One may believe that the exoemission maximum is associated with a diffusion of vacancies towards the surface of specimen, and the transport of point defects occurs mainly through dislocations. There is a certain critical compressive stress which is needed to start the dislocation motion, it means the beginning of plastic deformation. It was hoped that the optical microscopy reveals the dislocation motion. From the simple conditions presented below we indicate that at the measuring conditions applied in this paper the occurance of the Lüders-Hartmann fronts and bands should be expected.

The sample in the form of a cylindrical rod which is loaded by the external force Z was taken into account (Figure 2). This force Z is a source of the normal stress, $\sigma = N/A$, and the tangent stress, $\tau = T/A$ (N and T are the normal and tangent components of the external force Z, respectively). The force Z acts on to each plane making an angle α with the tension direction (see Figure 2a). As it can be seen from Figure 2a and 2b for

$$\alpha = 90^\circ \quad N = Z \quad T = 0 \quad A = A_k;$$
$$\alpha \to 0^\circ \quad N \to 0 \quad T = Z \quad A \to \infty.$$

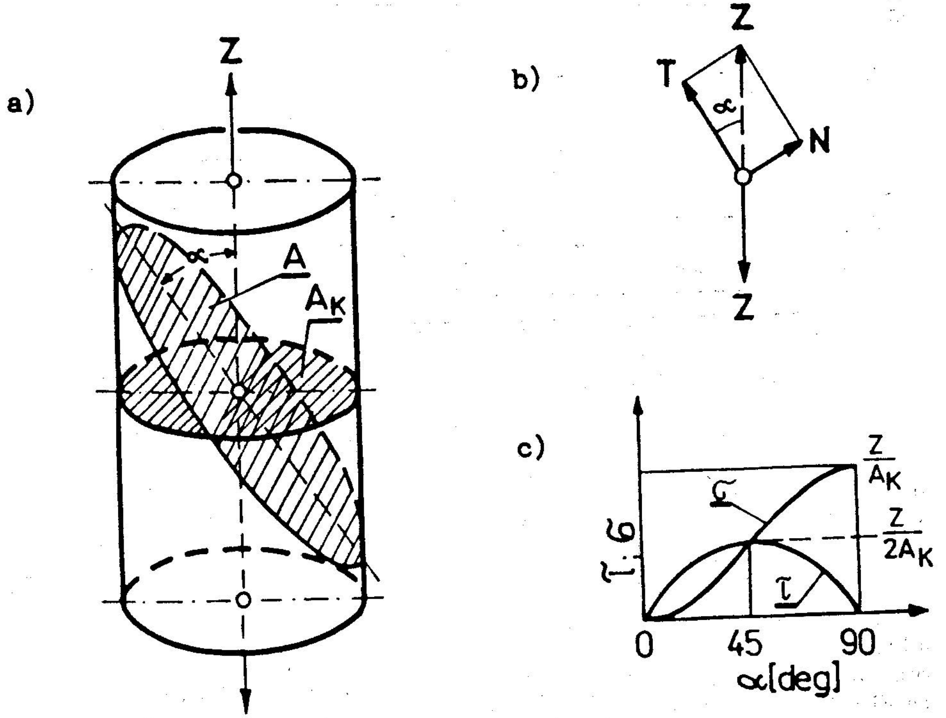

Fig. 2. Scheme of stress pattern normal and tangent for a cylindrical bar: a) section planes of cylinder: A_k- normal plane to the loading axis, A- sloping plane to the loading axis at the angle of α b) resolution of loading force Z on the A plane c) normal, σ and tangent, τ stress versus the angle α.

Generally, one can write

$$N = Z\sin\alpha \quad A = \frac{A_k}{\sin\alpha} \quad \sigma = \frac{Z\sin^2\alpha}{A_k}$$

$$T = Z\cos\alpha \quad A = \frac{A_k}{\sin\alpha} \quad \tau = \frac{Z}{A_k}\sin\alpha\cos\alpha$$

The normal stress σ increases from 0 to Z/A_k for α increasing from 0 to 90°. The tangent stress τ increases from 0 for $\alpha = 0$ to the maximum value of $Z/2A_k$ for $\alpha = 45°$ and then decreases to zero for $\alpha = 90°$ (Figure 2 b). So with the increase of the tension force Z, due to the fact that $\tau = \tau_{\max}$ for $\alpha = 45°$, the critical shear stress on crystallographic planes and in crystallographic directions is overtaken and the slip of the crystallographic planes takes place in aluminium samples investigated. This consideration is confirmed by the photographs of the specimen surface for different stage of deformation which are shown as an example in Figure 3. As it was expected, the specimen subjected to small uniaxial tension ($\varepsilon = 8\%$) shows on its surface the

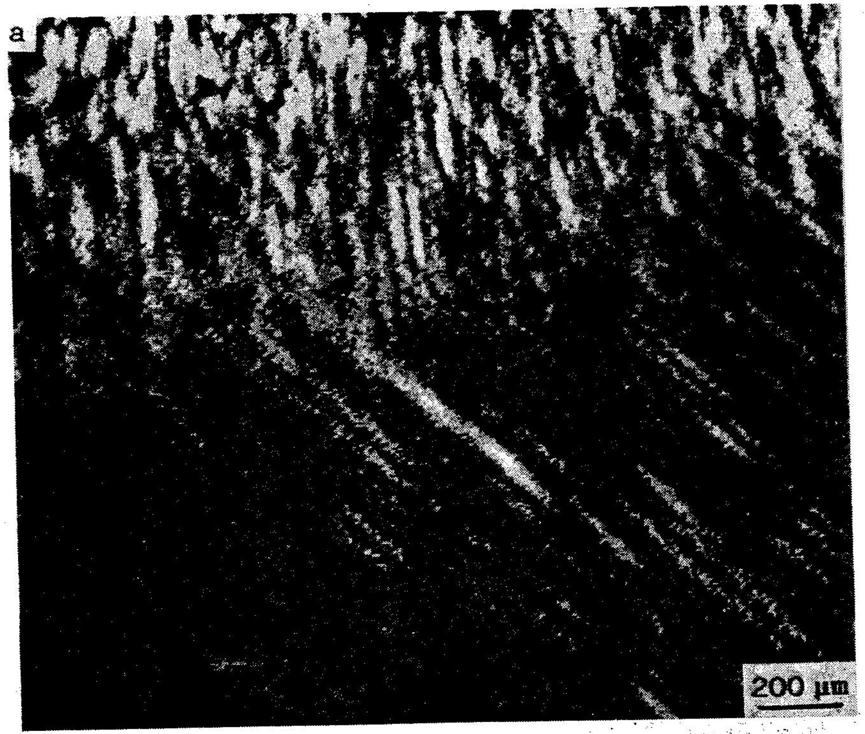

Fig. 3. Slip bands observed on the surface of aluminium: a) and b) parallel slip bands ($\varepsilon = 8\%$); slip direction make the angle of 45° with the tensor axis.

visible deformation region with the slip net of the Lüders-Hartmann bands which with the tension direct make angle of 45° (see Figure 3 a). Applying the uniaxial deformation higher than the yield point ($\varepsilon = 19\%$) leads to mutually perpendicular slip lines. Some of them are perpendicular to the generating crack and the other make the angle of 45° with the deformation axis (Figure 3b - 3d). Initiated, in macro scale, the cracks on the specimen surface get larger with the increase of the uniaxial tension.

As it results from the strength theory of materials, with the increase of the tensile force the mean distance between atoms increases. In many solids the destruction by fracture does not occur, but when the yield point is exceeded plastic deformation by the slip is observed. The dislocation motion is an elementary mechanism of plastic strain. Motion of single dislocation reveals a value of slip "b" only. The analysed macroscopic strain must be connected with the motion of many dislocations. Point defects are transported along dislocation line to the surface, where as a emission centre emit electrons traped. Created microinterstices are then changed. Induced electric field comes into existence above the emitting surface.

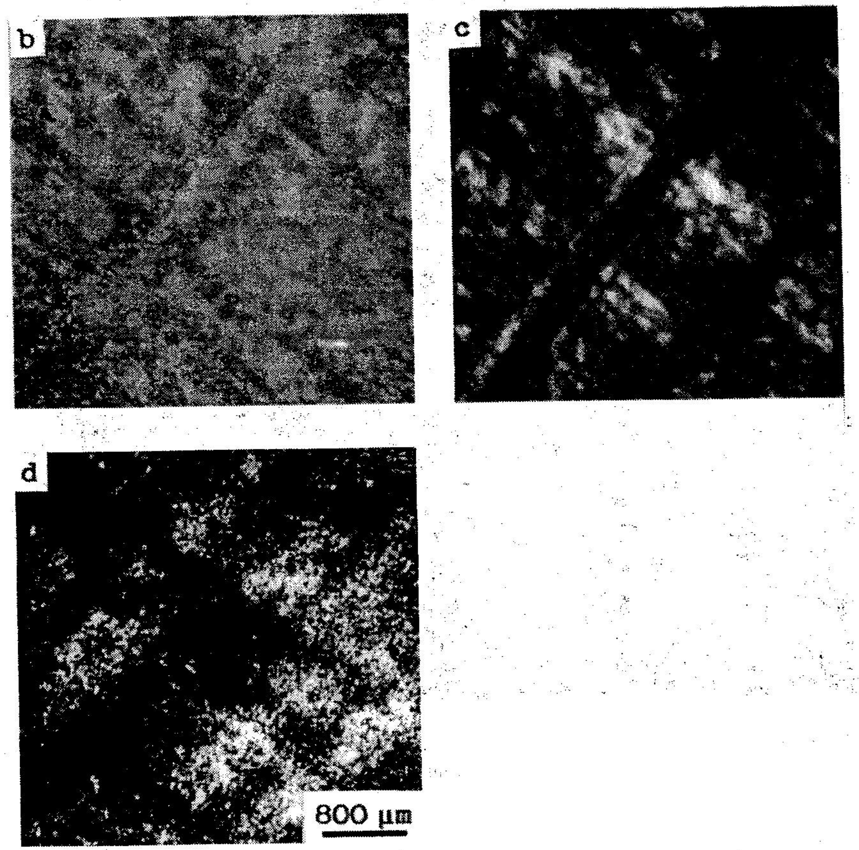

Fig 3. (continued)

Observation in the polarized light of the surface specimen covered with the polar liquid crystal and subjected to considerable deformation ($\varepsilon = 21\%$) show a distinct bright crack image (Figure 4 a). With the relaxation of deformation ($\Delta\varepsilon = 1.5\%$, $t_{relax} = 10s$) the intensity of the reflecting light gets lower (compare Figures 4a and 4b). We believe that the decrease of the light intensity of the crack is connected with the decrease of the electric field intensity induced by the crack during the deformation relaxation process of the material. The relatively fast relaxation process may be due rapid an increase of the dislocation amount and connected with them the high gradient of flow stress particularly observed at the yield point. At the yield point the slip lines are generated very intensively and this is accompanied by the increase of the exoelectron emission (see Figure 1). We believe this paper univocally proves the hypothesis regarding the

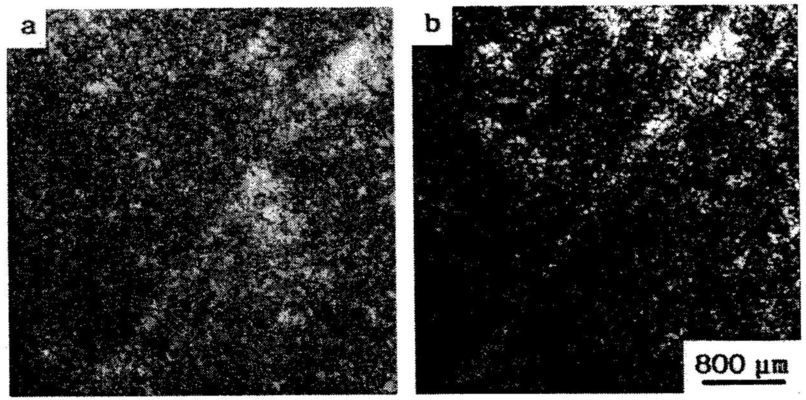

Fig. 4. Image of the electric field over the microcrack of the deformed aluminium sheet covered with the liquid crystal: a) $\varepsilon = 21\%$, b) $\varepsilon = 21\%$ and their relaxation $\Delta\varepsilon = 1.5\%$, $t_{relax} = 10s$.

nature and explained the kinetic of exoelectron emission phenomenon accompanying plastic deformation of metals.

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