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Abstract

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ON THE INITIAL STAGE OF PLASTIC DEFORMATION OF POLYCRYSTALS

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To study the initial stage of plastic deformation of metallic polycrystals, the present work employed the method of photoelastic coatings ([1]). With this method one can not only obtain a qualitative picture of the development of plastic deformation, but also determine, with high accuracy, the magnitude and direction of local deformations.

The investigations were carried out on flat specimens of austenitic steel of grade 1Kh18N9T with a grain size of 0.2-0.5 mm. An epoxy resin of grade ED-6 was used as the coating material. The resin was cured after being applied to the surface of the specimen; maleic anhydride was used as the hardener. The thickness of the photoelastic film was 0.03-0.07 mm. Such a film has good adhesion to the metal up to a deformation of the order of 2%, while retaining its elastic properties.

Observations of the specimen in polarized light (with crossed polarizer and analyzer) during deformation showed that before loading the specimen appears completely dark; the application of load causes bright regions to appear, the intensity of which increases with increasing stresses in the specimen. Up to stresses of the order of 10 kg/mm^2, i.e., approximately up to half the yield strength $\sigma_{0.2}$, the bright regions are very weak and disappear completely after removal of the load, which indicates the elastic nature of the deformation. Measurements of the isoclinic parameter showed that the directions of the principal strains under elastic loading vary within fairly wide limits: the angle of deviation of the direction of the principal strain ε_1 from the tensile direction in different grains reaches $\pm$12-15° (in individual cases even $\pm$20-25°); at the same time, the range of variation of the strain direction within individual grains, as a rule, does not exceed 5-7°.

At stresses of 10-12 kg/mm^2, brighter regions appear in individual grains in the form of thin parallel lines, which remain even after the load is removed. In unpolarized light no traces of deformation are detected in these regions. Only upon further loading, when the stresses in the specimen reach 15-20 kg/mm^2, and the average elongation of the specimen is about 0.2%, do ordinary slip traces, visible in unpolarized light, appear in places corresponding to the bright bands.

Fig. 2

Figure 1: Fig. 2

Simultaneously with the formation of bright bands situated at considerable distances from one another, which reflects the process of coarse slip, continuous bright regions arise in individual areas of grains, most often near boundaries; in these regions it is very difficult, and sometimes impossible, to distinguish separate bands (Fig. 1).

Plastic deformation in the grains proceeds very inhomogeneously from the very beginning. In addition to the inhomogeneity caused by the concentration of deformation in individual slip packets, the averaged deformation of individual regions of the grains also varies in magnitude and direction within fairly wide limits. Regions near grain and twin boundaries are most often sites of especially strong concentration of deformation.

Plastic deformation nucleates especially easily and develops intensively in the region of certain twin boundaries. At such boundaries, deformation occurs in the initial period by shears along planes parallel to the twinning plane, often on both sides of the boundary.

Fig. 2. Field of isoclines in one of the grains. The numbers indicate the angle between the tensile direction and the direction of the principal strain ε_1. Elongation of the specimen $\varepsilon = 1.2\%$

When the elongation of the specimen reaches 1.0–1.5%, the optical path difference at sites of deformation concentration attains values at which these regions acquire interference coloration, and then the picture of the deformation distribution becomes especially clear. In order of increasing optical path difference, the white color changes to yellow, then to orange, red, violet, blue, etc.

With increasing overall deformation of the specimen, the inhomogeneity of its distribution in individual grains with respect to direction increases (see Table 1). At a specimen deformation of 1.2%, the interval of variation of the direction of the principal strain ε_1 in individual grains reaches 23–33°, and the deviation from the tensile direction is ±15–25°.

An idea of the character of the change in the direction of deformation within an individual grain is given by the scheme of isoclines (lines of equal deformation directions) in Fig. 2. It is seen that in this grain the maximum deviations of the direction of ε_1 from the tensile direction are observed at grain junctions and near the intersection of a boundary by twins.

Table 1

Values of the angle α (in deg.) between the tensile direction and the direction of the principal strain ε_1. $\varepsilon_{\text{spec}}$ —relative elongation of the specimen; σ —stress; α_1 and α_2 —limiting values of the angle α

Figure 1

Figure 2: Figure 1

Figure 1

Figure 3: Figure 1

Grain No.	$\sigma =$ 16 kg/mm^2 α_1	$\sigma =$ 16 kg/mm^2 α_2	$\sigma =$ 16 kg/mm^2 $\lvert\Delta\alpha\rvert$	$\sigma =$ 0 (load removed) α_1	$\sigma =$ 0 (load removed) α_2	$\sigma =$ 0 (load removed) $\lvert\Delta\alpha\rvert$	$\sigma =$ 28 kg/mm^2; $\varepsilon_{spec} =$ 1.2% α_1	$\sigma =$ 28 kg/mm^2; $\varepsilon_{spec} =$ 1.2% α_2	$\sigma =$ 28 kg/mm^2; $\varepsilon_{spec} =$ 1.2% $\lvert\Delta\alpha\rvert$
1	−12	−7	5	–	–	–	−10	+3	13
2	−1	+11	12	–	–	–	−5	+18	23
3	−11	+7	18	–	–	–	−24	+20	44
4	−5	+13	18	–	–	–	−14	+17	31
5	−2	+13	15	–	–	–	−5	+21	26
6	−9	+6	15	–	–	–	−10	+16	26
7	−25	−5	20	–	–	–	−21	+11	32
8	−9	0	9	–	–	–	−19	+6	25
9	−9	0	9	−17	−5	12	−9	+12	21
10	−16	0	16	−25	−4	21	−21	+7	28
11	−14	−6	8	−24	−10	14	−17	+7	24
12	−11	+3	14	−18	+1	19	−15	+9	24
13	−14	+7	21	−14	+7	21	−8	+25	33
14	−12	+14	26	−14	+14	28	−11	+17	28
15	−5	+6	11	−7	+24	31	0	+10	10
16	0	+4	4	−10	+2	12	−18	+1	19
17	−5	+15	20	−15	+5	20	−14	+17	31

Note. Under the action of a load corresponding to a stress in the specimen of 16 kg/mm^2, the first 8 grains underwent only elastic deformation.

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Fig. 1. View of a section of the specimen in polarized light. Stress in the specimen $\sigma = 25$ kg/mm^2; elongation $\varepsilon = 0.65\%$; 85×

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Fig. 1. X-ray diffraction patterns of specimens. a –Ga_2Se_3, b –alloy $4Ga_2Se_3 + CuGaSe_2$; v –alloy $9Ga_2Se_3 + AgGaSe_2$

Quantitative data on the distribution of deformation in individual microregions of the specimen were obtained on the basis of measurements of the optical

Fig. 3

Figure 4: Fig. 3

Fig. 4

Figure 5: Fig. 4

path difference acquired by the ordinary and extraordinary rays during double (forward and reverse) passage through the film. Within the limits

Fig. 3. Magnitude and direction of deformation near a twin boundary:
1 $-\varepsilon_1 - \varepsilon_2$; **2** $-\alpha$;
a $-\sigma = 15$ kg/mm^2, $\varepsilon_{1\,\mathrm{rev}} - \varepsilon_{2\,\mathrm{rev}} = 3 \cdot 10^{-3}$;
b $-\sigma = 22$ kg/mm^2, $\varepsilon_{1\,\mathrm{rev}} - \varepsilon_{2\,\mathrm{rev}} = 15 \cdot 10^{-3}$

Fig. 4. Distribution of deformation along a line intersecting several grains: solid line $-\varepsilon_1 - \varepsilon_2$; dashed line $-\alpha$; $\sigma = 28$ kg/mm^2, $\varepsilon_{1\,\mathrm{rev}} - \varepsilon_{2\,\mathrm{rev}} = 18 \cdot 10^{-3}$

of elastic deformations of the film, the relation between the maximum shear (the difference of the principal deformations) and the optical path difference is expressed by the equation

$$\delta = 2dK(\varepsilon_1 - \varepsilon_2),$$

where δ is the optical path difference, d is the film thickness, and K is the deformation coefficient of photoelasticity.

Figure 3 shows the deformation distribution near a twin boundary for the case of easy nucleation of shears along planes parallel to the twinning plane. The relation between the magnitude of the maximum shear and the direction of the principal deformation is evident.

Figure 4 presents a case in which the direction of measurement intersects three grains, two of which contain twins. Here the deformation reaches its greatest value to the left of the origin, where the measurement line intersects three twin boundaries and passes near a grain boundary.

Conclusions

1. The photoelastic-coating method makes it possible to measure deformations within individual grains of a polycrystal. The accuracy in determining the magnitude of the difference of the principal strains is $5 \cdot 10^{-4}$; the accuracy in determining the direction of the principal strains is 1°.

2. The plastic deformation of steel 1Kh18N9T proceeds from the very beginning by slip along slip planes; no displacement of grains relative to one another along the boundaries was detected.

3. The distribution of deformation among grains and within individual grains is very nonuniform over the entire range of investigated values of specimen deformation (from 0 to 2.0%). The maximum values exceed the minimum ones by 10–15 times.
4. The fact has been established that plastic deformation readily nucleates and develops near some twin boundaries.

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References Cited

1. B. A. Kuznetsov, *Zav. lab.*, No. 5, 610 (1957).

Note: Figure translations are in progress. See original paper for figures.