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A theory of flow stress, including the yield strength, $\sigma_y$ suggested in [1,2,3] is proposed for the class of polycrystalline (PC) materials with equilibrium and quasi-equilibrium defect structure (EDS), which is established in the PC material after series of $N_0=N_0(\alpha; T)$ identical combinations (denoted by the letter $\alpha$) of mechanical tests of severe plastic deformation at fixed temperature $T$ and characterized by stabilized scalar dislocation density (SDD) and average grain size $d$. We calculate both the stationary SDD $\rho(b, d, T)$

$$
\rho = \langle c \rangle M d^2 \left( \frac{m_0 \epsilon}{G b^2} - 1 \right)^{-1} \frac{1}{M} = \frac{1}{2} G b^2 \kappa_b T
$$

and suggest a way to calculate $\epsilon$-evolution of an equilibrium SDD $\rho_0$ in PC sample under quasistatic loading depending on the average size $d$ of a grain in the range of $10^{-8}$–$10^{-2}$ m, on grain boundaries disorientation (for effective)

$$
\rho_0 = \langle c \rangle M d^2 \left( \frac{m_0 \epsilon}{G b^2} - 1 \right)^{-1} \frac{1}{M} + \sigma(\epsilon) \quad (2)
$$

In (1), (2) the quantities $G$, $b$, $k_b$, $M(\alpha)$, $<\langle c \rangle$, $m_0$, $\epsilon$ are respectively the shear modulus at given T; length of the least Burgers vector from the most probable dislocation ensemble, Boltzmann constant, and effective (with $b_0 = b(\epsilon + 1)$) scales for forming the unit dislocation, strain degree, polyhedral parameter and strain. The analytical dependence is realized within a disclination-dislocation mechanism in approximation of single dislocation ensemble for given phase and $T$. It is based on a statistical model of Boltzmann-like distribution (smoothly dependent on a strain $\epsilon$) for discrete energy spectrum in each grain of a single-mode one-phase PC material with respect to quasi-stationary levels under plastic loading with the highest level equal to the energy of dislocation with maximal length. The difference of equilibrium SDD, $\rho_0$, leads to a flow stress for simple case of isotropic GB distribution from the Taylor strain hardening mechanism

$$
\sigma(\epsilon) = \sigma_0(\epsilon) + \alpha_m G b \frac{m_0 \epsilon}{2 G b^2} \left( \frac{m_0 \epsilon}{G b^2} - 1 \right)^{-\frac{1}{2}} + \sigma(\epsilon), \quad m = 3.05
$$

which contain (for $\epsilon = 0.002$) the normal stress $\sigma(\epsilon)|_{\alpha=0} = \sigma_0(\epsilon) + \sigma(\epsilon)$ and anomalous Hall–Petch relations [4] respectively for coarse (CG) and nanocrystalline (NC) grains. The Hall–Petch coefficient $k(0,0.002)$ determined from experiments for single-mode PC samples with quasi EDS permits to express in the CG limit yet not exactly (within a theory) determined parameter $m_0$ for $\sigma_0$

$$
\kappa(0,0.002) = \sigma(0,0.002) \frac{\epsilon}{\alpha_m G b} = \frac{\sigma_0(\epsilon)}{\alpha_m G b} \quad \alpha_m G b = \frac{\epsilon}{\alpha_m G b} = \frac{\alpha_m G b}{\alpha_m G b} = \frac{\alpha_m G b}{\alpha_m G b} = \frac{\alpha_m G b}{\alpha_m G b}.
$$

The yield strength $\sigma(\epsilon)$ gains a maximum at flow stress values for an extreme grain size $d_0$ of the order of $10^{-8}$–$10^{-7}$ m

$$
\sigma_0(\epsilon, T) = b_0 \frac{G b \left(1 - \epsilon \right)}{2 \alpha_m G b}
$$

The maximum undergoes a shift to the region of larger grains for decreasing temperatures, reveals temperature-dimension effect for such class of PC materials with EDS. Coincidence is well established between the theoretical and experimental data on $\sigma_y$ for the materials with EDS with BCC ($\alpha$-Fe), FCC (Cu, Al, Ni) and HCP ($\alpha$-Ti, Zr) crystal lattices with closely packed grains at $T=300$K.

The graphic dependence $\sigma_y = \sigma_y(d_0^{1/2})$ for the hard (crystalline) phase of PC aggregates of $\alpha$-Fe, Cu, Al, Ni, $\alpha$-Ti, Zr with closely-packed randomly oriented grains, to be homogeneous with respect to their size (single-mode case) at $T=300$K, are presented on the Fig. 1.

Remarkably, the values of $d_0(0.002, 300)$ for $\alpha$-Fe, Cu, Al, Ni, $\alpha$-Ti, Zr in the Table 1, are in complete agreement with the range (both empirical and theoretical) of critical size values for the average diameters of grains $d_{cr}$ for above PC samples (listed, e.g., in Ref. 6 [Table 2.6, pp. 110–
and in Ref. 7), ranging from 5–10 nm to 20–50 nm, particularly, for \(d_{cr}(Cu)=10\) nm and \(d_{cr}(Ni)=20\) nm and \(d_{cr}(300;Ni)=22.6\) nm (see Ref. [1]).

Table 1. The values \(\sigma_0, \Delta \sigma_{\text{m}}, (\sigma_{\text{m}}/\sigma_0), E_d^{1/2}, k, m_\alpha, \alpha\) in BCC, FCC and HCP PC metal samples with \(d_{cr}, b, G\) from (3)-(5)

<table>
<thead>
<tr>
<th>CL</th>
<th>BCC</th>
<th>FCC</th>
<th>HCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>(\alpha)-Fe</td>
<td>Cu</td>
<td>Al</td>
</tr>
<tr>
<td>(\sigma_0, \text{MPa})</td>
<td>170 (annealed)</td>
<td>70 (anneal.); 380 (cold-worked)</td>
<td>22 (anneal. 99.95%); 30 (99.5%)</td>
</tr>
<tr>
<td>(b, \text{nm})</td>
<td>(\frac{\sigma}{E}d=0.248)</td>
<td>(\frac{\sigma}{E}d=0.256)</td>
<td>(\frac{\sigma}{E}d=0.286)</td>
</tr>
<tr>
<td>(G, \text{GPa})</td>
<td>82.5</td>
<td>44</td>
<td>26.5</td>
</tr>
<tr>
<td>(T, K)</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>(k, \text{MPa}\cdot\text{m}^{3/2})</td>
<td>(0.55-0.65) ((10^{-5}-10^{-3}\text{m}))</td>
<td>(0.25 \times 10^{-4}) ((-10^{-3}\text{m}))</td>
<td>(0.15 \times 10^{-4}) ((-10^{-3}\text{m}))</td>
</tr>
<tr>
<td>(\alpha)</td>
<td>–</td>
<td>0.38</td>
<td>–</td>
</tr>
<tr>
<td>(E_d^{1/2} = \frac{1}{2}Gd^{1/2})</td>
<td>(\text{eV})</td>
<td>3.93</td>
<td>2.31</td>
</tr>
<tr>
<td>(d_{cr}, \text{nm})</td>
<td>14.9-19.5</td>
<td>9.8</td>
<td>8.71</td>
</tr>
<tr>
<td>(D_{\text{m}}, \text{nm})</td>
<td>2.29-2.56</td>
<td>1.34</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Figure 1. Graphic dependence for generalized HP law with an additional upper scale with size of grains \(d\) given in \(\mu\text{m}\). Upper axis \(d\) is changing within range \((\alpha;0)\) with the inverse quadratic scale and the correspondence \((100;1.6;0.1;0.044;0.025;0.011;0.006;0.004;0.003) \mu\text{m} \leftrightarrow (0.005;0.015;0.1;0.15;0.2;0.3;0.41;0.5;0.57) \text{nm}^{1/2}\) for the respective values on the lower axis. By the colored cross for \(\alpha\)-Fe (black), Cu (red), Ni (green) it is shown the experimental maxima

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