STRAIN HARDENING OF ALLOYS WITH FACE-CENTERED CUBIC LATTICE

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A brief review is given of the peculiarities of the strain hardening of face-centered cubic (fcc) alloys as compared with pure metals. The fundamental equations connecting the strain hardening characteristics to the quantitative characteristics of the dislocation structure and the slip trace picture are considered in application to alloys with a high friction stress of a nondislocation nature \( \tau_F \). The shape of the strain hardening curves of alloy mono- and polycrystals is analyzed; it is shown that it depends substantially on the stress level \( \tau_F \).

Strain hardening theory has been developed primarily for pure metals [1-8]. The study of the strain hardening of alloys has been directed principally towards the clarification of the regularities of this phenomenon and the investigation of the hardening mechanisms inherent to alloys of a different nature. There is a number of surveys and monographs in which a detailed analysis is given of the strain hardening mechanisms for alloys of a different nature [9-15]. Significant progress in the study of the interconnection between the evolution of microstructure in the mentioned strained alloys and their macroscopic properties has put on the agenda the question of a generalized theory of strain hardening of pure metals and alloys of different nature. The present paper is devoted to a discussion of such a generalization.

**Strain Hardening Curves of fcc Alloys**

The strain hardening curves of alloy monocrystals differ substantially from the flow curves of pure metals. Since a detailed description of the regularities of strain hardening of alloys of a different nature is given in a number of review papers and monographs [9-20], let us designate just the most general peculiarities of the strain hardening curves of alloys.

1. **Higher Flow Macrolimits than in Pure Metals.** It exceeds the yield point of pure metals by one-to-two orders in concentrated solid solutions and two-phase alloys.

2. **Prolonged Stage with Low Strength Coefficient.** This stage is complex in alloys. It can include: a) a long flow area associated with propagation of the Liiders-Chernov band; b) the easy slip stage, analogous to the easy slip stage in the pure metals case; c) a prolonged section with monotonic growth of the strength factor. Little attention has been paid to the last singularity of the flow curves, which has been noted in many alloys. The existence of a long section, going over from stage I to a linear hardening stage [21-25], has been noted in many papers. In some cases attempts have been made to divide the strain hardening curve of alloys into several linear hardening substages with the strength factor growing from stage to stage.

There are no detailed investigations of the change in the strength factor of monocrystals of alloys with strains. In many cases a monotonic growth in the strength factor can be observed up to the beginning of stage III or to crystal rupture (examples of such curves are presented in Fig. 1) on the curves \( \sigma = f(\varepsilon) \) or \( \tau = f(\theta) \) (\( \varepsilon \) is the relative strain, \( \sigma \) is the tensile or compressive stress, \( \tau \) is the tangential stress in the slip plane, and \( \theta \) is the shear strain). In such cases the strength factor at the end of the stage with the growing strength factor, where the tendency of the strength to approach the linear is noted, is taken as the strength factor in stage II. Graphs of the dependence \( \theta = d\sigma / d\theta \) on the degree of strain of Ni\( _3 \)Fe alloy single crystals in two states, disordered and ordered, are presented in Fig. 2.


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Fig. 1. Strain curves of monocrystals of the alloys Ni+21.5 at. % Al (1) [24], Ni+19 at. % Al (2) [24], and Ni$_3$Fe (3, 4) (data of L. A. Teplyakova and V. A. Starenchenko) [3] ordered state; 4) disordered state.

Fig. 2. Curves of $\theta$ vs $\alpha$ for Ni$_3$Fe alloy single crystals with strain axis orientation [117]: 1) ordered state; 2) disordered state.

Fig. 3. Dependence of the quantity $d\varepsilon/d\sigma$ on the stress $\sigma$ for polycrystalline alloys Ni+20 at. % Mn (1) [32] and Ni+16 at. % Al (2) [34].

Fig. 4. Dependence of the dislocation density to the $1/2$ power on the flow stress for the alloys: a) Ni$_3$Al (1 – $T_{str}=20^\circ$C, 2 – $400^\circ$C) [96]; b) Ni$_3$Fe (1 – ordered state, 2 – disordered state, $T_{str}=20^\circ$C [67]; c) Ni$_3$(Fe, Cr) (1 – ordered state, 2 – disordered state, $T_{str}=20^\circ$C) [56].