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PLASTIC FLOW AUTOWAVES IN SOLIDS: MAIN REGULARITIES

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During recent decades, the nature of plasticity was approached by taking into account the nonlinearity and activity of the deforming medium as well as its ability to remember external action. According to Seeger and Frank [1], the medium's structuring capacity is also of principal importance. In view of the above, the plastic flow can only be dealt with in the frame of synergetics [2]. Due to the theoretical developments [3] and the experimental observations [4], a space-time approach was brought to the study of solids plasticity, which provided an efficient tool for accounting the plastic flow regularities. It is contended that the conventional dislocation theory is evidently outdated; hence, elaboration of a more sophisticated physical theory of plasticity and setting out its basic theses is necessary.

The plastic flow exhibits a tendency to localization, which is its distinctive feature observable in the range of deforming stresses $\sigma_y \leq \sigma \leq \sigma_u$ (here σ_y is yield point and σ_u is ultimate strength). A one-to-one correspondence is found to exist between the types of localization pictures (patterns) on the one hand and the stages of deformation hardening on the other. The flow stages are distinguished using the dependence $\theta = E^{-1} \cdot d\sigma/d\varepsilon = \theta(\varepsilon)$ where E is elastic modulus. The analysis of the pattern types and of the changeover in the emergent patterns suggests that we deal with autowave processes, which are solutions of parabolic differential equations in partial derivatives of the kind

$$\dot{\varepsilon} = \varphi(\varepsilon) + D\varepsilon'', \quad (1)$$

where $\varphi(\varepsilon)$ is a nonlinear function, so-called 'point kinetics', which describes a relaxation act involved in the deformation in an arbitrary point of the deforming medium; D is a coefficient of spatial redistribution of strains having dimensionality $\text{m}^2 \cdot \text{s}^{-1}$.

The generation of autowave process of plastic flow is given by Eqn. 1; the emergence of a series of localized plasticity fronts can be traced experimentally. Under given loading conditions, $\dot{\varepsilon} = \text{const}$ in Eqn. (1). With growing deformation, however, the nonlinear function $f(\varepsilon, \sigma)$ will decrease due to the depletion of mobile dislocations, which necessitates introduction of the term $D\varepsilon''$ for a certain deformation level in order to preserve the plastic flow continuity. It can be seen from Table 1 that for every type of autowave process there is a specific pattern emergent at the respective process stage.

Table 1. Deformation Work Hardening Stages and the Respective Autowave Types

Work hardening stage	Hardening law	Type of autowave process
Yield plateau	$\theta \approx 0$	Switching autowave
Linear deformation hardening	$\theta = \text{const}$	Phase autowave
Parabolic deformation hardening	$\theta \sim \varepsilon^{1/2}$	Stationary dissipative structure
Prefailure	$\theta \sim \varepsilon^n; n < 1/2$	Collapse of autowave

The above correspondence suggests that the plastic flow process can be regarded as a regular evolution of localized plasticity autowaves. The characteristics of autowaves, i.e. propagation rate, V_{av} , dispersion relation, $\omega(k)$, and wavelength dependence of structural parameters, e.g. grain size, $\lambda(\delta)$, were determined experimentally in the studies conducted previously with the aid of speckle interferometry technique developed by Sjö Dahl [5].

Analysis was made of the quantitative characteristics of localized plastic flow. Using the characteristics of autowaves and those of elastic waves, the following invariant relation was obtained

$$\left\langle \frac{\lambda \cdot V_{aw}}{\chi \cdot V_i} \right\rangle = \frac{1}{2}, \quad (2)$$

where χ is interplanar distance and V_i is the propagation rate of transverse ultrasound waves. The angular brackets indicate that averaging was performed for nineteen studied materials, i.e. pure metals, alloys, alkaline halide crystals and rocks. An analysis suggests that the invariant (2) plays an important role in the description of plastic flow development in solids. The point is that common rearrangement of Eqn. (2) enables one to obtain the main properties of autowaves propagating in the deforming medium. The results obtained in the previous experimental studies are listed in Table 2 for the linear work hardening stage. Moreover, the invariant directly relates the characteristics of elastic waves (χ and V_i) on the one hand and the parameters of localized plasticity autowaves (λ and V_{aw}) on the other hand, which indicates that the two kinds of wave processes are intimately associated. The latter thesis might form the basis for a two-component model of plastic flow. Built into the working of the model will be the effect of acoustic emission by plastic flow and the acoustic-plastic effect [6].

Table 2. Principal Characteristics of Deformation Autowaves

Property of Autowave Process	Relation
Autowave propagation rate, V_{aw} , as a function of θ	$V_{aw} \approx V_0 + \Xi/\theta \sim \theta^{-1}$
Dispersion relation, i.e. dependence of frequency, ω , on wave number, k	$\omega = 1 + k^2$
The dependence of autowave length, λ , on grain size, δ	$\lambda = \lambda_0 + \frac{a_1/a_2}{1 + C \cdot \exp(-a_1\delta)}$
Differential equation for plastic flow kinetics	$\dot{\varepsilon} = f(\varepsilon, \sigma) + D\varepsilon^n$
Mobile dislocation density as a function of deformation	$\rho_{mob} \sim \varepsilon^{-1}$

The experimental data was analyzed. In extended discussions we developed a new model of localized plastic flow in solids. According to the general theses, the plastic flow localization is a process of self-organization of the deforming medium. The general theory of self-organization processes admits a hypothesis of the medium spontaneously separating into information and dynamic subsystems. Acoustic emission signals play the role of information subsystem; these are generated due to the relaxation plasticity acts (shears) to cause new plasticity acts. The shears play the role of dynamic subsystem which is responsible for form changing. Thus, the deformation phenomena can be addressed in the frame of proposed theory to enable an adequate qualitative and quantitative description.

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