Macroscale Plasticity Parameter of Metals and Alloys

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The existence of localized plasticity autowaves has been proved via a speckle photography technique specially modified for these purposes [1], which allows determining the field of displacement vectors in a deformable sample and calculating the components of the plastic distortion tensor on this basis. It is also found experimentally that the localization of plastic flow behaves as a spontaneous stratification of the deformable medium into macroscopic deforming and non-deforming volumes alternating in the sample space [1]. The combination of these volumes forms an evolving macroscopic autowave pattern of localized deformation, that is, a localized plasticity pattern. Localized plasticity autowaves are characterized by a length $\lambda \approx 10^{-2}\ m^2$ and a propagation velocity inversely proportional to the coefficient of strain hardening $V_{aw} = V_0 + \Xi/\theta$. The law of dispersion of autowaves is expressed as $\omega \sim 1 + k^2$. In these relations, V_0 and $\Xi -$ are constants, $\omega -$ is the frequency, and $k = 2\pi/\lambda -$ is the wave number.

In the new approach, attempts were made to take into account that plastic deformation occurs in an open system. This is because the energy received by the sample from the source (testing machine) during testing is partly returned to the drain. Attention was also paid to the nonlinearity of the deformable medium, resulting from the complex form of the stress-strain ($\sigma(\varepsilon)$) dependence, as well as its activity and disequilibrium associated with the presence of local sources of potential energy distributed over the volume (elastic fields of emerging and relaxing stress concentrators) [2].

Thus, the present work aims to analyze the role of macroscopic effects of plastic deformation in the development of the plastic flow and to establish their functional relationship with the lattice characteristics of the deformable medium.

Introduction of elastic-plastic deformation invariant

It is evident that the ratios of spatial and velocity scales of plastic and elastic deformation processes $\lambda/\chi \approx V_t/V_{aw} \approx 10^7$ have the same order of magnitude. Hence, the products λV_{aw} and χV_t, whose dimensions of the kinematic viscosity $m^2 s^{-1}$ coincide with those of the coefficients $D_{\varepsilon\varepsilon}$ and $D_{\sigma\sigma}$ in Eqs. (1) and (2), will be assumed characteristic of these processes.

$$\begin{cases} \dot{\varepsilon} = f(\varepsilon) + D_{\varepsilon\varepsilon}\varepsilon'' \ (1), \\ \dot{\sigma} = g(\sigma) + D_{\sigma\sigma}\sigma'' \ (2), \end{cases}$$

According to the experimental data in Fig. 1, the product λV_{aw} characterizing the autowaves of localized plasticity at the stage of linear strain hardening depends in a complex way on the properties of the deformable medium. To a lesser extent, this applies to the magnitude χV_t. Thus, it seems expedient to analyze the ratio of quantities $\lambda V_{aw}$and χV_t for various materials. The base for generalizing this kind of data is given in Table 1 including updated and supplemented experimental results from Refs. [1, 3-4].

The experimental values of the invariant $\hat{Z}$ were subjected to statistical analysis according to the method described in work [5]. For this purpose, the data were transformed into a variation series. As a null hypothesis, the $\hat{Z}$ distribution was suggested to be normal. This assumption was tested using the Kolmogorov-Smirnov criterion by applying STATISTICA software.

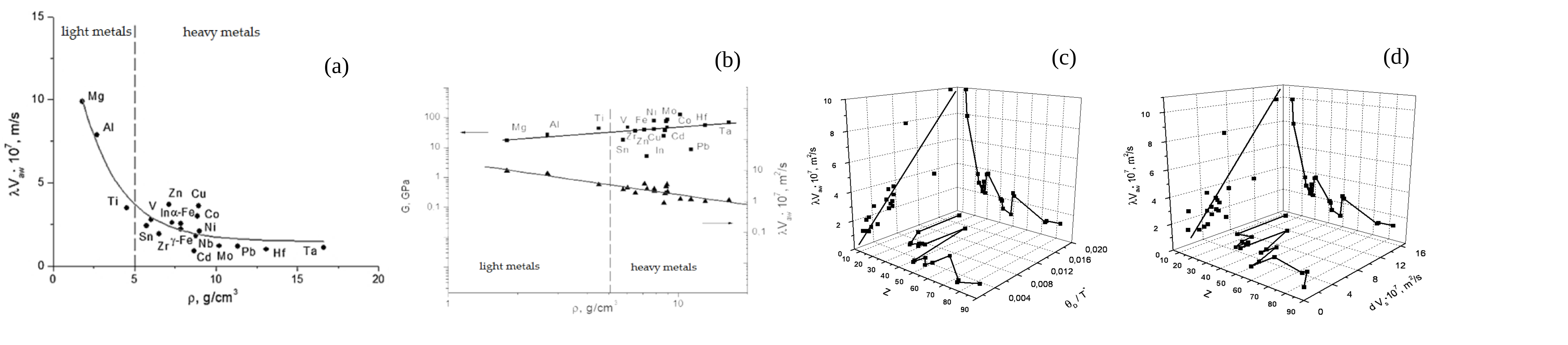

Fig. 1. The dependences of product λV_{aw} and shear modulus G on (a, b) density, (c) temperature and atomic number; (d) the correlation of products λV_{aw} and χV_t with atomic number Z

The standard normal distribution z_j for the *j*-th rank of a variable with $N = 38$ observations was calculated as $z_j = F^{-1}[(3j-1)/(3N+1)]$, where F^{-1} is the inverse function of a standard normal distribution, transforming the normal probability p into the normal value z.

According to Fig. 2, the $\hat{Z}$ distribution is indeed normal and is characterized by the following parameters: $\hat{Z}_{\min} = 0.2$, $\hat{Z}_{\max} = 1.1$, and $\sigma^2 = 0.040$.

Based on these results, a dimensionless ratio can be derived as

$$\left\langle \frac{\lambda V_{aw}}{\chi V_t} \right\rangle = \hat{Z} = 0{,}46 \pm 0{,}03 \approx {}^1/_2 \qquad (3),$$

here and hereinafter called the elastic-plastic deformation invariant. It links the parameters of elastic (χ and V_t) and plastic (λ and V_{aw}) deformation. The relationship (3) is valid for linear strain hardening stages of the materials, when $\sigma \sim \varepsilon$.

When describing the development of localized plasticity at the stage of linear strain hardening of materials, an elastic-plastic deformation invariant can be introduced, linking the characteristics of the elastic and plastic components of total deformation. The relationship of these components is determined by the fact that the formation of the autowave structure of a localized plastic flow is an ordering (self-organization) of the deformable medium and should proceed with a decrease in the entropy of the system.

The invariant plays the role of the basic equation of the autowave theory of plasticity. It implies a number of corollaries that correctly describe the basic laws of the autowave process of localized plastic flow. In particular, the speed and dispersion of localized plasticity autowaves, the circumstances causing localization phenomena during deformation, the scale effects, the dependence of the autowave length on the grain size and so on.

Thus, an experimental study of the patterns of localized plastic flow, as well as the concept of plastic flow as a structure formation, allowed one to explain various important regularities of plasticity of solids from a single point of view, which was earlier possible with only the introduction of numerous particular models.

Funding
This work was supported within the framework of the State Task of ISPMS SB RAS (project no. FWRW-2021-0011).

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