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Physical nature of metals longevity in the dynamic failure phenomenon

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Abstract. Methods of non-linear physics allowed determination of universal attributes of non-equilibrium systems, conditioned by collective effects and self-organization phenomena in the arising dissipative structures. The paper presents data on the rate of centers formation of a number of studied metals, time-temperature regularities of the dynamic failure process, that permit modeling metals behavior under laboratory conditions and predict time boundary of maintaining functional properties under extreme conditions (longevity range $t \sim 10^{-6} - 10^{-10}$ s).

1 Introduction

Problems of describing the failure phenomenon under various loading conditions represent one of the most important tasks of modern physics and are acute in applied issues of solid body physics, thermodynamics and statistical physics, mechanics of deformable continuums. As a rule, relaxation of strongly non-equilibrium states is accompanied by dynamic destructive processes [1–4]. At small degrees of deviation from equilibrium the relaxation processes are determined by kinetics mechanisms that are described by the classic kinetics instrument. For example, for gases when chaotization occurs, one can go over to a single-part distribution function. In the failure physics in a quasi-static longevity range the time interval up to failure is determined by the time of critical fluctuation formation, for example, energy leading to destruction of a part of atomic bondings. Above-mentioned processes are ergodic. At high degrees of deviation from the equilibrium state relaxation is specified by the processes which are not characteristic of initial (quasi-stationary) ones, but by new arising relaxation processes possessing a time-scale hierarchy. The phenomenon of dynamic failure refers to such a type of relaxation processes [2].

2 Results and discussion

Earlier in our works the main attention was paid to formulation of topology conditions of limiting transition – the last process stage which was corresponded to a concept of threshold in the percolation model of dynamic failure. However from the point of view of failure process forecasting and determining of time boundary of maintaining functional properties it is important not only the final phase, but also preceding process history. Therefore, acute is a study of the whole sequence of events, prior to threshold state and determining of time boundary of maintaining of functional properties of a number of metals under extreme conditions [1–4]. This is a goal of work. In non-linear dissipative media, to which belong the metals in the process of dynamic failure, there diminishes amount of freedom degrees. This means that in the system there occurs self-organization of structure elements, characterized by large-scale correlations. The parameter of the order characterizes a transition from non-correlated matter state to the correlation one. Failure centers density $f(t)$, depending on time, on the failure threshold, when the coherence of the body under failure changes, is an order parameter. A significant increase of density of failure centers $f(t)$occurs at the final stage of the failure process on times $t \sim 0.9 \cdot t_r$, where t_r – time of failure [4]. One of the most important results in dynamic turbulence theory was detection of universal attributes in scenario of transition of laminar flow to the turbulent one [5]. Universal properties are determined by the dynamic system type (flow properties) and do not depend on its details, similar to тому, как properties of transition to self-organization in critical phenomena do not depend on конкретного вида Hamiltonian of micro-scale flows, states. In the most simple case self-organization – spontaneous origin of stable structures (dissipative structures) in non-equilibrium dissipative media [6]. From this universality it follows that for description of basic types of critical behavior one can use simple models, demonstrating the basic ways of transition to self-organization [1,2]. It seems to us, that less studied are scaling properties of transition to turbulence, mixing, dispersion, developed in such flows, as for example, jets, shearing layers. Such types of flows are formed, for example, at high-intense action to samples with perturbations, for example, in the form of pyramidions. Establishment "coherent", hierarchy structures (in these flows) indicate the possibility of building adequate models of metals dynamic failure. Papers [1, 2] show that from the property of self-similarity there follows a bound between a critical pressure amplitude P and material longevity, which is determined as

$$P(t)^{\gamma} t = \text{const}, \qquad (1)$$

where $\gamma \approx 3.8$. Just this condition determines the possibility of modeling the process of dynamic failure under laboratory conditions at real process time scaling [2]. The clustering process one can study both depending on the number of elementary events, and in time as well. At this the process kinetics knowledge is required.

Centers formation rate $J(t)$ of a number of studied metals, as there demonstrate study results, presented in the paper [3,4], possess close values (see Fig. 1).

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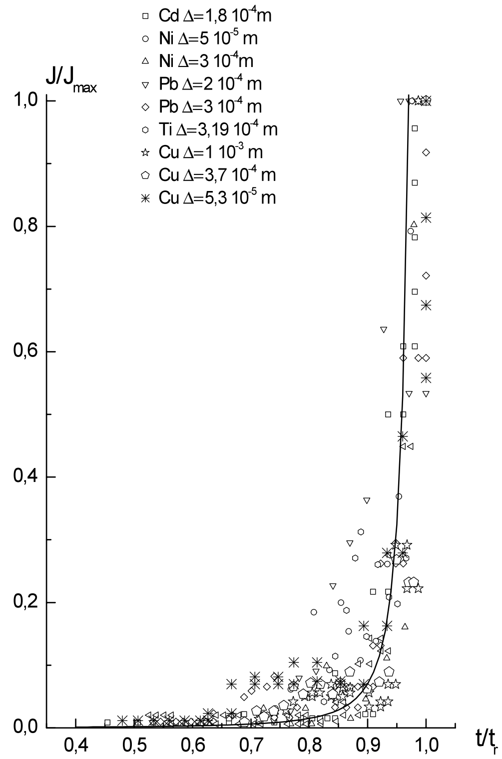

Fig. 1. The rate of centers formation of a number of metals of different thickness in the coordinates t/t_r, $J(t)/J_{max}(t_r)$, t_r–failure time markers–experimental data [3,4].

The longevity is summed as a stage of awaiting for failure centers occurrence $t_{wait.}$ and time $t_{f.}$ of clustering of failure centers cascade (see Fig. 1), when connectivity возникает связность appears in the failure centers system, and a percolation cluster appears. Papers [3,4] demonstrated that $t_{wait.} \gg t_f$. In view of this correlation determination of time t_{wait} estimates the time boundary of maintaining the functional properties of metals under extreme conditions. Taking into account this correlation, one can suppose, that at a stage of awaiting the cluster of failure centers the probability theory formalism is acceptable (processes of failure centers occurrence are independent). The type of function $J(t)$ for different metals in the longevity range $t \sim 10^{-6} \div 10^{-10}$ s is similar to the function type, describing the modes with sharpening, or systems behavior near the critical point.

On the basis of determined time-temperature regularities (private for each metal) by the grounded calculation-and-theoretical way there were obtained data on the failure boundary in the longevity range $t \sim 10^{-6} \div 10^{-10}$ s, in the range of initial temperatures $T_0 \sim 4K \div 0.8T_m(T_m$ – melting temperature) in the coordinates longevity t, dynamic invariant $I = P_{cr.}(t)/\Gamma\rho(H + L_m)$, where $P_{cr.}$– critical pressure, leading to failure, Γ – Gruneisen parameter, ρ – density, H – enthalpy and L_m – melting heat (see fig. 2, a) and in the coordinates $E(T_0)/(H(T_0) + L_m)$, $lg(1 - T_0/T_m)$ (see Fig. 2, b) [1–4]. On Fig. 2, there is given a time dependence of the dynamic failure process of a number of metals under the action of relativistic electron beams (REB) and laser radiation short pulses. Let us note that critical density of the absorbed energy, causing failure, for example, of metals Al, Ta, Cu under the action of short pulses of laser radiation and exposure to REB agree (see Fig. 2, a). Fig. 2, shows temperature dependences of the process of dynamic failure of a number of metals under the action of REB, which are of a similar type [4].

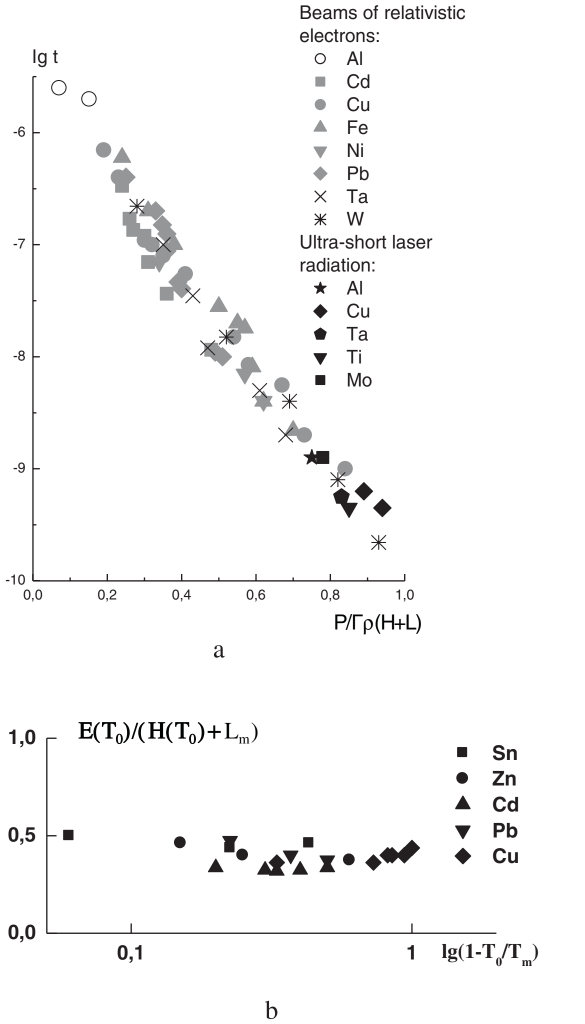

Fig. 2. Dependences of dynamic failure process: a – temporary; b - temperature.

3 Conclusions

The unique mechanism of dynamic metals failure process – the lost of systems connectivity (sample) by clustering the failure centers cascade – a unique order parameter and similar space dimension, where the process flows, proves the possibility for predicting metals behavior under extreme conditions. The above said specifies the scale invariant properties of dissipative structures and governs the universal metals behavior in the dynamic failure phenomenon at different time intervals at different time-amplitude characteristics of external action. As a result of studies conducted it was shown that physical nature of metals longevity under extreme conditions is specified by the time of formation of critical failure centers cascade concentration being a percolation cluster.

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