THE EFFECT OF RELAXATION AND PREHISTORY ON THE BEHAVIOR OF THE STRUCTURAL ORDER PARAMETER IN THE COURSE OF PLASTIC TWISTING

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When a plastic deformation of any type is applied, four zones can be separated. The first zone is characterized by elastic behavior only. Plastic deformation becomes substantial within the second one. The third zone is an area of prevailing plastic deformation. The fourth zone associated with a fracture, we do not consider here. It should be noted that a conventional criterion of the separation of the first zone and the second one is absent. This fact is determined by substantial effect of plasticity on the behavior of the material even under small deformation.

All the of aforesaid is also related to plastic deformation of twisting about a crystal axis. The further analysis is based on the explicit dependence of the modulus of twisting moment *M* on the number of revolutions *N*. To establish the dependence, generally, the description of the evolution of structural defects [1,2] and their effect on the plastic yield stress of the twisting moment is required. The problem becomes more complex, so simplifying assumptions should be made. Namely, at high *N*, the system achieves constant stationary values. Thus, the modulus of the twisting moment *M* depends on the number of revolutions *N* as a function characterized by a horizontal asymptote

$$M = \alpha_1 * th(\alpha_2 * N) \tag{1}$$

where α_1 and α_2 are phenomenological constants. The choice is based on the fact of constant M within the third zone because the twisting moment is determined by the elastic component of deformation only.

Suppose that the second-order phase transition results in formation of a highly-symmetrical state characterized by vector order parameter q and non-zero Lifshits invariants. Non-equilibrium thermodynamic potential is written as

$$\Phi = \frac{b_1}{2} q^2(N) + \frac{b_2}{4} q^4(N) + \frac{b_3}{6} q^6(N) + \gamma_1 M^s \left(q_x \frac{\partial q_y}{\partial z} - q_y \frac{\partial q_x}{\partial z} \right) + \\ + \gamma_2 M^r \left(\left(\frac{\partial q_x}{\partial z} \right)^2 + \left(\frac{\partial q_y}{\partial z} \right)^2 \right) + q^2(N) \frac{1}{\Delta N} \int_{N-\Delta N}^{N} A(x) q^2(x) dx + \Phi_{el} \tag{2}$$

where γ_i *(i = 1, 2)*, b_i *(i = 1, 2, 3)* are phenomenological constants, Φ_{el} is the potential of elastic interaction related to the elastic tensor. The terms that include derivatives describe spiral structure generated as a result of twisting. The next to last term in (2) accounts for the pre-history, factor *A(x)* determines the law of distribution of interaction in the past. In particular, the law can describe the preceding states totally or partially as well as the rate of decrease in the interaction (exponential, elliptical, linear etc.). In the present work, *s = 6*, *r* = 2 [3].

Account of deformation implies that the system passes to a non-equilibrium state as a result of a process. Transition to the equilibrium state is due to a relaxation in some time period. At the finite relaxation time and fast external action, the states are non-equilibrium and the modulus of the structural OP is modified. The delay of the equilibrium state can be described by the Landau-Khalatnikov equation. We analyze three variants of time dependence of the number of revolutions here: $N_1 \sim t,\ N_2 \sim t^2,\ N_3 \sim \sqrt{t}$. Equation (6) was solved numerically using the MatLab package.

1) Without of prehistory account. The results of theoretical analysis of time dependence $q(t)$ at varied twisting conditions are presented in Fig.1. The dash-dotted line is the linear dependence $N_1 \sim t$, the dashed line is the square dependence $N_2 \sim t^2$ and the dotted line marks the rotation with negative acceleration $N_3 \sim \sqrt{t}$. For the sake of comparison, solid line illustrates $q(N)$ without relaxation (the system is in the equilibrium state at any twisting moment) at $N \sim t$ (steady rotation).

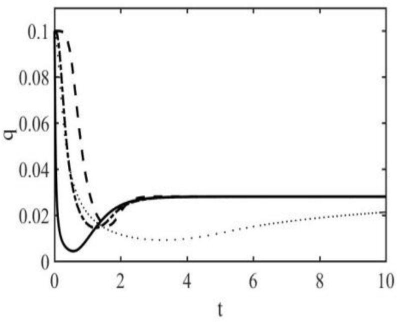

Figure 1 - Rotation without an account of prehistory

From the viewpoint of physics, a stable state of a crystal is characterized by some energy minimum. At high temperature, the global minimum is of highly symmetrical state. At the temperature drop, an additional minimum arises that is associated with a state of low symmetry. Under further temperature decrease, the low-symmetry phase is of lower energy. If the system is located below the temperature of transition in the area of lability, where two minima coexist, and the twisting deformation is applied, the elastic component enhances the energy of the system. As a result, the minima of high- and low-symmetry phases start convergence and the reverse transition to a high-symmetry state becomes favorable. Thus, the modulus of the OP is reduced.

Further, increase if *N* reduces a contribution of the elastic component according to (1). A spiral structure becomes the most favorable state of the system.

As a result, the energy of the crystal decrease and the modulus of the OP rises. In the steady mode, the contribution of the elastic component stays constant, being accompanies by a fixed energy of the system and the modulus of the OP becomes independent of the number of revolutions. As shown in Fig.1, an account of possible relaxation results in an increase in the modulus of the structural OP and a shift of the minimum of $q(t)$ towards later moments.

The lowest shift is generated by the linear dependence $N_1 \sim t$, the highest one is related to $N_3 \sim \sqrt{t}$. One should note unusual behavior of the dotted line (exponential distribution) characterized by a plateau at minor values. This fact is determined by low twisting rate in this area, so the energy of the sample stays almost the same. The ratio of the energies in the highly-symmetrical and low-symmetrical phases is stable, resulting in local stability of the structural order parameter. In the last two cases, the twisting rate in the vicinity of zero time is higher. The equalization of the energies of highly-symmetrical and low-symmetrical states proceeds faster and the value of $q(t)$ is reduced faster, too. The case of $N_3 \sim \sqrt{t}$ is of the highest rate and a reduction of $q(t)$ is faster, consequently.

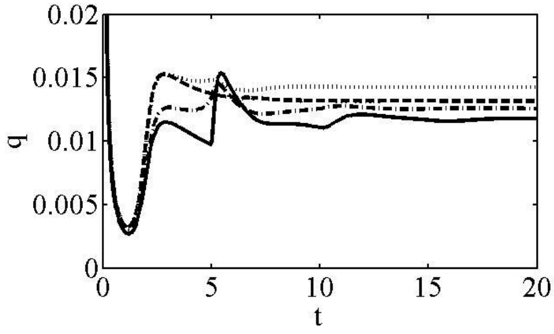

Figure 2 - Steady rotation. Small value of the parameter of system relaxation

2) In view of prehistory. We consider the case of $N_1 \sim t$ (rotation at a constant angular velocity). From the viewpoint of Physics, due regard to the prehistory means that there exist areas with the frozen preceding values of the twisting moment within the crystal. In Fig 2, the results of theoretical calculations inclusive of four distribution laws of prehistory are presented. The solid, dotted, dash-dotted and dotted lines mark rectangular (*ΔN*<*N*), exponential, elliptical (*ΔN*<*N*) and linearly descending (*ΔN*<*N*) distribution law, respectively. A sharp change of the monotonous solid line in the vicinity of $t \sim 5{,}5$ arises due to the fact that preceding states become not involved to the prehistory and their contribution is of the same intensity. With respect to this fact, in the third zone, $q(t)$ demonstrate substantial convergent oscillations in the vicinity of the minimum of the non-equilibrium potential that is an evidence of gradual approaching the equilibrium. The first peak is determined by a sharp rejection of sharply changeable initial states. The next minimum arises as a result of the rejection of the states in the vicinity of $t \sim 5{,}5$. An analogous feature is less pronounced in the rest of cases because the rejections occur at small parameter of distribution $A(x)$. The anomaly is almost invisible at the exponential distribution law.

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