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KINETICS OF VARIATION OF ELECTRICAL RESISTANCE AND YIELD STRENGTH IN TECHNICALLY PURE NICKEL DUE TO LOADING IN THE ELASTIC RANGE AT 300 – 77 K

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Results of a study of the variation in yield strength and electrical resistance of technically pure nickel in different initial structural states as a function of the test temperature and applied stress are presented. Possible mechanisms affecting the physical and mechanical properties of the studied nickel are explained.

Keywords: resistivity, yield strength, technically pure nickel, microplasticity.

INTRODUCTION

Thermal, mechanical, and other kinds of external action violate the initial quasi-equilibrium state of actual crystals and promote changes in the field of internal stresses and distribution of dislocation segments in the volume and potential barriers over the height. This changes the strain resistance of the crystals and other properties of the material in subsequent tests.

In many cases the microplasticity of metals determines the value of the macroplastic yield strength, the susceptibility to brittle fracture, the creep behavior, and the relaxation in fatigue tests of the materials. Allowance for the microplasticity is especially important for parts operating under conditions of rigid constraints with respect to the size and the structure.

Defects in actual crystals result in changes in the crystal bodies even in the elastic loading range.

The aim of the present work consisted in studying[3] the changes in the electrical resistance and yield strength of technically pure nickel loaded in the elastic range at 300 – 77 K.

METHODS OF STUDY

We studied technically pure nickel. Sheets rolled to a thickness of 2.0 – 2.2 mm were used to cut specimens with functional part 2 × 2 × 16 mm in size along the direction of the rolling, which were subjected to mechanical and electrolytic treatment. Prepared specimens were annealed at 1000°C (the first batch). A part of the specimens was quenched from 1070°C in water and used as a second batch. In order to determine the mechanical properties the specimens were loaded in a rupture machine at appropriate temperatures.

The specimens of the first batch were loaded in a step manner from $\sigma_1 = 0.1\sigma_{0.2}$ to $\sigma_1 = \sigma_{0.2}$ at 300 and 77 K. The quenched specimens of the second batch were loaded in a similar manner in the elastic range at room temperature. After removing the load the specimens were subjected to natural aging at 20°C for 20 h and then tested for tensile strength at 300 K. The change in $\sigma_{0.2}$ was determined in terms of the difference in the yield strength under the corresponding load and the yield strength in the initial annealed state, i.e., $\Delta\sigma = \sigma'_{0.2} - \sigma_{0.2}$.

RESULTS AND DISCUSSION

It follows from the experimental results obtained (Fig. 1) that the behavior of the yield strength is affected by such factors as the value of the preliminary load, the test temperature, and the initial structural state.

As the load on the specimen in the elastic range increases, the value of $\sigma_{0.2}$ decreases with respect to that of the initial specimen. The highest decrease in $\sigma_{0.2}$ is observed at $\sigma_1 = (0.5 - 0.6)\sigma_{0.2}$. Further growth in the load lowers the softening, and at $\sigma_1 = (0.9 - 1.0)\sigma_{0.2}$ the metal undergoes strain hardening.

It is known that the distribution of locking points on dislocations depends on the value of the external stress and on the temperature. Under the action of the load applied the

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[3] The studies have been performed with the use of the equipment of the Collective Use Center of the Belgorod State University.

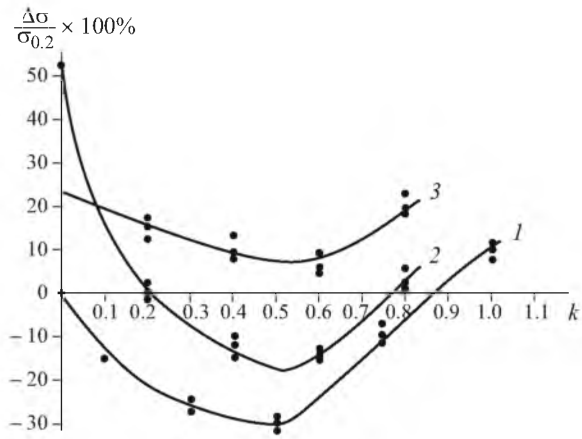

Fig. 1. Variation of the yield strength after loading of annealed specimens in the elastic region at a temperature of 300 K (*1*) and 77 K (*2*) and of quenched specimens at 300 K (*3*). Here $k = \sigma_l/\sigma_{0.2}$ is the loading factor.

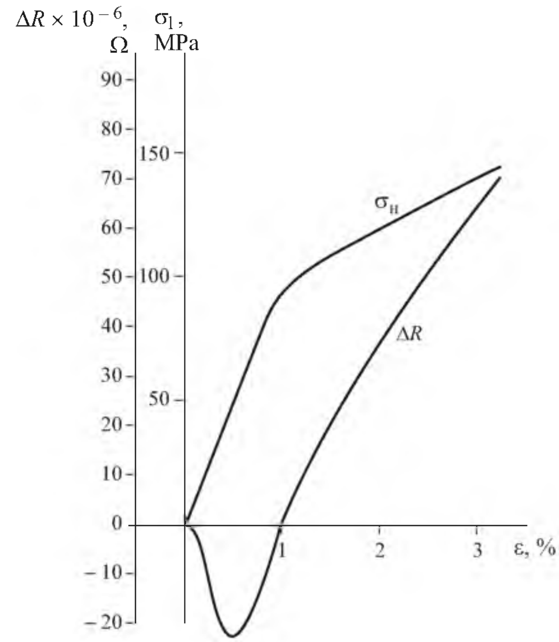

Fig. 2. Variation of electrical resistance ΔR in the process of loading (σ_l is the load, ε is the strain) of initial nickel specimens at room temperature.

locking points start to be redistributed along the dislocation line and this redistribution occurs until the potential energy and the entropy come into equilibrium [1]. The redistribution of the locking points increases their density near the locking nodes of dislocations, and this changes the length of the dislocation segment.

Redistribution of locking points occurs in a wide temperature range (Fig. 1). However, the degree of the softening is higher at 300 K (curve *1* in Fig. 1). Lower decline for one and the same batch is observed at 77 K (curve *2* in Fig. 1). Growth in the density of defects in the volume of the crystal after quenching from the pre-melting temperature is accompanied by displacement of the locking points and, with them, of the dislocations, and this causes substantial lowering of the softening (curve *3* in Fig. 1).

It can be assumed that this is accompanied only by bending of the dislocation line without intense multiplication of dislocations in the process of interaction with potential barriers inside the crystal.

In addition to vacancies and vacancy complexes formed due to quenching from a high temperature, the potential barriers may include accumulations of impurities, dislocation jogs, etc.

External stress promotes multiplication of dislocations if its value is sufficient for the dislocation segments free of locking points to be able to emit dislocations [1, 2].

A study of the behavior of electrical resistance is a possible method for determining the interaction between different defects of crystal structure.

It is known that the value of electrical resistance depends on the presence of defects in the volume of the crystal and on the temperature at which the measurement is performed.

Different defects affect the resistance differently. For example, point defects make a greater contribution into scattering of electrons than dislocations [3]. In its turn, the scattering of electrons on dislocations is proportional in the general case to the dislocation density [4] and depends on the type of dislocations, on the mutual orientation of the wave vector of the scattered electron and of the direction of the dislocation lines, and on the relative change in the volume occupied by the defects.

It follows from the experimental data obtained (Fig. 2) that the electrical resistance decreases upon growth in the applied stress at room temperature; the resistance is lowest at $\sigma_l = 0.5\sigma_{0.2}$. When the load applied in the elastic range is increased still more, the decline of the resistance decreases; passage to the plastic strain range first restores the resistance to the initial value and then increases it.

Study of the variation of electrical resistance in the process of loading in the elastic range allows us to understand the kinetics of the variation of the structure of the metal studied. The studies performed in [5] have dealt with materials deformed in the macroelastic range with considerable residual strains. The data of this work cover the elastic range at specific experimental temperatures. Comparing the behavior of the stress σ_l with the variation of the electrical resistance ΔR in the deformation process (Fig. 2) we can see a qualitative identity of the behavior of the curves. When mechanical action not exceeding the value of $\sigma_{0.2}$ at the test temperature is stopped, the old mechanical and electrical parameters are recovered.

CONCLUSIONS

1. Softening of technically pure nickel at stresses not exceeding the yield strength occurs due to redistribution of

locking points over dislocation lines and bending of dislocations. The extent of the softening depends on the structural state of the metal, the temperature, and the value of the applied stress.

2. Variation of the yield strength and electrical resistance in a wide temperature range indicates that the determining processes of the motion of dislocations and their interaction with defects remain sensitive to the temperature of the specimen until very low temperatures.

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