ELASTIC AND INELASTIC PROPERTIES OF SINGLE CRYSTAL Ni-35.6wt%W IN THE TEMPERATURE RANGE OF 51–300 K

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MOTIVATION

As promising materials in the design of modern aircraft engines and gas turbine power plants, nickel-based single-crystal alloys are currently widely used, which are capable of operating under extreme conditions of high temperatures, high mechanical loads, and have high corrosion resistance and durability. The use of directionally solidified (DS) columnar grains, and later single crystal (SC) alloys, resulted in a significant increase in creep and crack resistance due to the elimination of weak grain boundaries oriented transverse to the load direction. An important factor is also the possibility of choosing the crystallographic direction of growth of <001> nickel alloy single crystals with the lowest modulus of elasticity along the turbine blades, which significantly increases the resistance to thermomechanical fatigue in regions with limited thermal expansion. In general, the absence of transverse grain boundaries, combined with a lower elastic modulus, leads to an increase in the durability of structural elements from 3 to 5 times [1]. Besides of orientation, the mechanical properties of single crystals can be affected by the dendritic structure of the alloys. Depending on the manufacturing and processing techniques chosen, products identical from a crystallographic point of view can have a different dendritic structure. In particular, the first-order dendrite axes can be located both parallel and perpendicular to the sample axis. The properties of alloys in these directions can also be different.

The study of the elastic and inelastic properties of materials can provide important and useful information about the effect of sample structure on the dynamic moduli of elasticity and sound absorption in crystals [2].

EXPERIMENT

In the present work, we have studied temperature behavior in the temperature range of 51–300 K of the dynamic Young's modulus E and the logarithmic decrement δ of the longitudinal standing sound waves with the strain amplitudes $\varepsilon_0 = 6\cdot10^{-8}$ in the single-crystal samples of the Ni-35.6 wt.%W alloy at the frequencies about 73 kHz. The measurements were made with the samples in the form of rectangular rods of the size 3×3×30 mm3 cut from a single-crystal turbine blade. The longitudinal axis of the samples coincided with the crystallographic direction <001>. For acoustical measurements, the two-component composite vibrator techniques was used [3]. Longitudinal standing waves were excited in the samples by the piezoelectric quartz transducers. Temperature dependences $\delta(T)$ and $E(T)$ were obtained during isochronous thermocycling in the temperature range investigated.

RESULTS AND DISCUSSION

Temperature dependence of the logarithmic decrement $\delta(T)$ in the single-crystal alloy sample Ni-35.6 wt.% W is shown in Fig. 1. It is characterized by very low decrement values (in the region of moderately low temperatures the decrement is δ ~ 10-5), which is apparently due to the perfect structure of the sample under study: the absence of grain boundaries, low dislocation density and their fixation by clouds of impurities (the so-called Cottrell clouds).

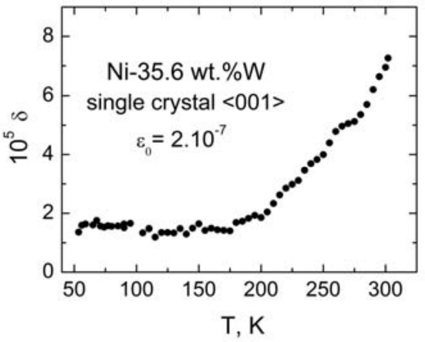

Fig. 1. Temperature dependence of the logarithmic decrement $\delta(T)$ in the single-crystal Ni-35.6 wt.% W.

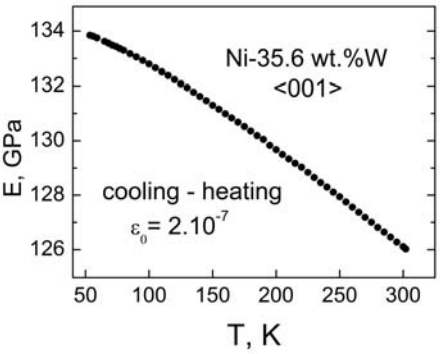

Fig. 2. Temperature dependence of the dynamicYoung's modulus $E(T)$ in Ni-35.6 wt.% W.

Temperature dependence of the dynamic Young's modulus $E(T)$ is shown in Fig. 2. It is clear from Fig. 2 that the $E(T)$ curve does not have any noticeable deviations from behavior that can be described in terms of classical ideas regarding the influence of thermal motion on the elastic properties of crystals. A theory for the temperature dependence of the elastic moduli was first proposed by Born and Huang [4,5]. According to that theory, this dependence is caused by a change in the potential energy of the lattice owing to its anharmonicity. In its limiting cases, the theory shows that the lattice phonon contribution should be proportional to T^4 for very low temperatures and to T for high temperatures. In perfect metals at low temperatures, the electronic contribution, proportional to T^2, plays an important role [6]. Later on, a number of attempts were made to represent the temperature dependence of the elastic moduli using empirical expressions. In particular, Varshni [6] suggested and justified theoretically empirical expressions for the temperature dependences of adiabatic elastic moduli over a wide range of temperatures for a very wide class of crystalline materials:

$$M(T) = M_0 - \frac{M_1}{\exp(\theta/T) - 1} \qquad (1)$$

Here M_0 is the limiting value of elastic modulus for $T\rightarrow0$, M_1 is a constant value depending on the material and deformation modes longitudinal, shear, or bulk, and θ is a characteristic temperature which also depends on the type of material. In crystals with simple phonon spectra, the characteristic temperature θ is close to the Einstein temperature $\theta_E \equiv h\nu_E = 0.75\cdot\theta_D$. Here h is the Planck constant, ν_E is the frequency of the harmonic oscillator in the Einstein model for a solids, and θ_D is the Debye temperature. Fig. 3 shows the fit of expression (1) to the experimental data, and Table 1 lists the parameters of the corresponding approximation, produced by the least-squares method.

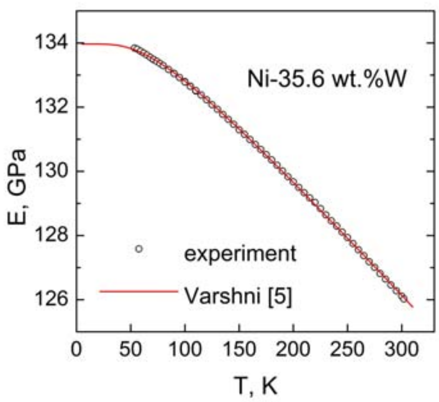

Fig. 3. Approximation of experimental data on the temperature dependence of the dynamic Young's modulus $E(T)$ by the Varshni expression (1).

Table 1. Parameters for approximating the temperature dependence of dynamic Young's modulus using the Varshni expression.

E_0, GPa	M_1, GPa	θ, K
134.0	7.48	201 ±2.5

CONCLUSIONS

- It is shown that the functional form of the obtained temperature dependences of the dynamic Young's modulus are corresponded to the classical concepts of the effect of thermal excitation of electrons and phonons on the elastic properties of a crystalIn the context of Varshni's consideration, empirical estimates of the Einstein temperature and other parameters of the approximation of the temperature dependence of the dynamic Young's modulus were obtained.
- Temperature dependence of the logarithmic decrement $\delta(T)$ in the single-crystal alloy sample Ni-35.6 wt.% W is characterized by very low decrement values (in the region of moderately low temperatures the decrement is of $\delta \sim 10^{-5}$), which is apparently due to the perfect structure of the sample under study: the absence of grain boundaries, low dislocation density and their fixation by clouds of impurities (the so-called Cottrell clouds). This also explains the absence of dynamic effects associated with thermally activated dynamic relaxations of defect structure elements (so called internal friction peaks) that were not detected in the whole temperature range studied.
- To establish the physical mechanisms of other observed features of the behavior of elastic and inelastic properties of the single crystal studied, additional studies are required..

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