STUDY OF CREEP DEFORMATION OF NI_3GE SINGLE CRYSTALS WITH [$\bar{2}34$] AND [$\bar{1}22$] ORIENTATIONS

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ABSTRACT

The creep properties of the Ni_3Ge alloy with [$\bar{2}34$] and [$\bar{1}22$] orientations were investigated by tests under constant–load at three different elevated temperatures 873, 923, 973K exceeding the temperature of the stress peak (T_p) and different compressive stresses. The examined crystals demonstrate two-stage creep curves. There is the primary stage where the strain rate decreases and the secondary one stays steady. Creep rates show normal temperature dependence, the creep rates increase with the increasing of temperature. The single crystals of the Ni_3Ge alloy with [$\bar{2}34$] and [$\bar{1}22$] orientations display high stability to changing temperature. The creep rates weakly depend on temperature.

KEYWORDS

Creep, intermetallics, ordered alloys, superstructure $L1_2$, single crystal, macrolocalization of deformation, Ni-base alloy

INTRODUCTION

The creep processes in superalloys attract attention due to the wide practical application of alloys under various conditions of service on the one hand, and scientific interest on the other hand. Studies of the creep deformation of ordered phases with $L1_2$ superstructure are done mainly in the Ni_3Al alloys as well as in other Ni_3Al-based alloys [1 - 5].

In this work the creep deformation of single crystals of the Ni_3Ge alloy with [$\bar{2}34$] and [$\bar{1}22$] orientations were investigated. The Ni_3Ge alloy possesses the positive temperature dependence on mechanical characteristics. The creep properties of this alloy were determined by tests under constant-load at temperatures higher than Tp, the temperature at which the peak yield stress being observed, and different compressive stresses. At high temperatures the single crystals of the [$\bar{2}34$] and [$\bar{1}22$] orientations show cubic slip in contrast to the orientation [001] which realizes only the octahedral sliding.

SPECIMEN, MATERIAL AND TESTING

Material

The Ni_3Ge single crystal was grown by the Chokhralski technique in an argon atmosphere from Ni-25at.% Ge alloy (N-0 grade Ni and 99.999 pure Ge). Specimens in the form of parallelepipeds 3.0 mm × 3.0 mm × 6.0 mm in size were cut from single crystal ingots by the electric spark method. The specimens were oriented to provide compression along the axes [$\bar{2}34$] and [$\bar{1}22$]. The orientation of crystal was determined by the Laue and X-ray diffraction methods. Before tests specimens were homogenized at T=1226 K for 48 hours.

Testing

The compression tests were carried out on an “Instron” machine at different temperatures (T=873, 923, 973 K). The specimens were heated in a resistance furnace. High-temperature tests were performed under vacuum at the pressure of (1–2)×10^{-3} mm Hg. The temperature was maintained within ±2 ºC. Creep was studied under different constant applied load. The directions of the compression axes of single crystals investigated coincided with the [$\bar{2}$34] and [$\bar{1}$22] directions. The applied stress (σ), cleavage stress ($\tau_{(111)[10\bar{1}]}, \tau_{(001)[1\bar{1}0]}$) in octahedral and cubic slip systems, shear stress in ratio to shear modulus τ / G, temperature *T*, homologous temperature T/T_{melt}, and shear stress in ratio to critical cleavage stress τ / τ_0 for each test are presented in Table 1.

Axis orientation	σ, MPa	$\tau_{(111)[10\bar{1}]}$, MPa	$\tau_{(001)[1\bar{1}0]}$, MPa	τ / G	T, K	T/T_{melt}	τ / τ_0
[$\bar{2}$34]	230	110	127	$3 \cdot 10^{-3}$	773	0,54	0,9
	230	97	112	$3 \cdot 10^{-3}$	973	0,68	1,1
[$\bar{1}$22]	230	94	108	$1,3 \cdot 10^{-3}$	873	0,61	1,1
	230	94	108	$1,3 \cdot 10^{-3}$	923	0,64	1,1
	230	94	108	$1,3 \cdot 10^{-3}$	973	0,68	1,2
	330	135	155	$2 \cdot 10^{-3}$	873	0,61	1,6
	330	135	155	$2 \cdot 10^{-3}$	923	0,64	1,6
	330	135	155	$2 \cdot 10^{-3}$	973	0,68	1,7

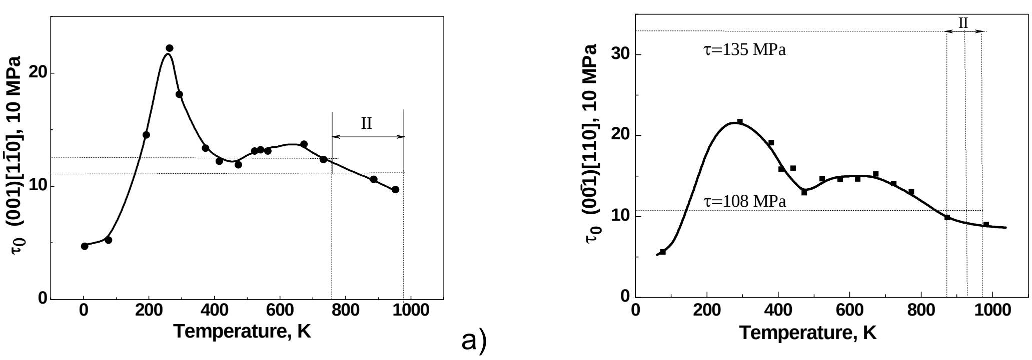
Table 1. Test conditions

The test temperature varied in the range = 0.54–0.68. It is seen in Fig. 1, the temperatures studied refer to a high-temperatures range that is above the peak-stress temperature.

EXPERIMENTAL RESULTS

Yield stresses

The Ni_3Ge alloy oriented along the axes [$\bar{2}$34] and [$\bar{1}$22] exhibit octahedral (111)[1 0 $\bar{1}$] and cubic (001)[1 $\bar{1}$ 0] slip. Fig.1 illustrates the yield stress temperature dependence. It



a) b)

Fig. 1: The yield stress temperature dependence of the Ni_3Ge single crystals with [$\bar{2}$34] (a) and [$\bar{1}$22] (b) compression axes. The thin curves show temperatures and stresses used in the creep test

displays a non-monotonous behaviour in several temperature intervals of the yield stress anomaly.

Each curve has two stress peaks [6, 7]. This is due to the fact that octahedral (111)[1 0 $\bar{1}$] and cubic (001)[1 $\bar{1}$ 0] slip at low temperatures are realised. However at temperatures being above the room temperature sliding is observed along cubic (001)[1 $\bar{1}$ 0] system. That points to essential distinctions between the [$\bar{2}$34], [$\bar{1}$22] orientations and the [001], [$\bar{1}$39] orientations.

The Ni_3Ge single crystals with the [001], [$\bar{1}$39] orientations mainly demonstrate octahedral slip. Thus, the [$\bar{2}$34] and [$\bar{1}$22] orientations of the Ni_3Ge single crystals are suitable for creep studying under cubic slip.

Creep curves

The axis orientation [$\bar{2}$34]. The creep curves for Ni_3Ge single crystals with compression axis orientation close to [$\bar{2}$34] at different temperatures 873, 923, and 973 K of applied-stress level σ=230 MPa are shown in Fig. 2 a. The single crystals exhibit cubic slip at temperatures and stresses mentioned above. Obtained curves have two stages. There are the primary (transient) creep stage, which demonstrates a gradual decreasing creep rate and the secondary (steady-state) creep stage with a constant creep rate. The creep rate

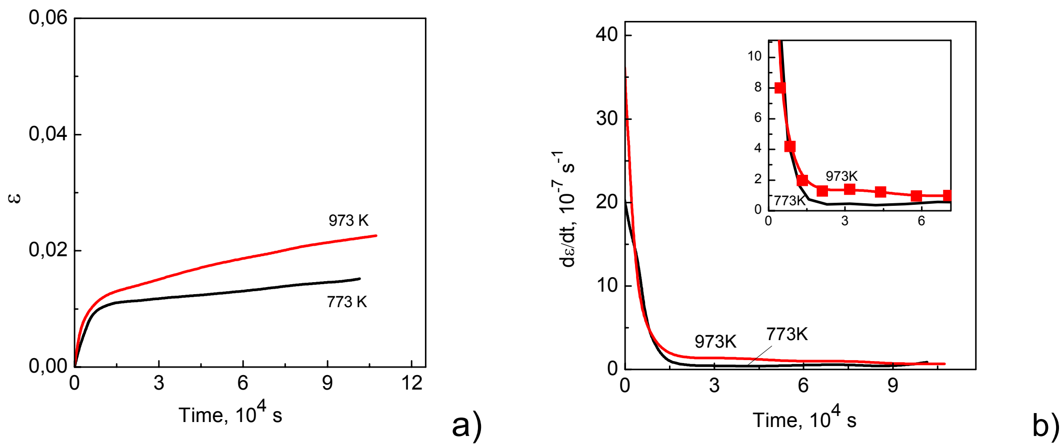


Fig. 2: Creep curves (*a*) and time dependence of the creep rate (*b*) for Ni_3Ge single crystals at different test temperatures, the compressive-strain axis [$\bar{2}$34], the applied stress σ=230 MPa.

decreases in primary creep stage taking a minimum value in the secondary creep stage. The tertiary stage was not observed and the “inverse creep” stage is lacking, too. In Fig. 2 b the curves of creep rate as a function of creep time are presented.

The axis orientation [$\bar{1}$22]. The creep curves for Ni_3Ge single crystals with compression axis orientation close to [$\bar{1}$22] at different applied-stress levels of 873, 923, and 973 K are plotted in Fig. 3.

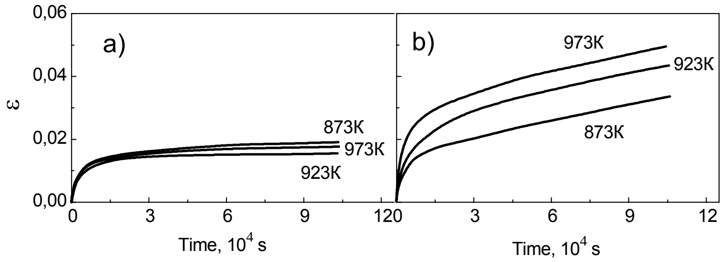


Fig. 3: Creep curves for Ni_3Ge single crystals at different test temperatures, the compressive-strain axis [$\bar{1}22$], the applied stress σ=230 MPa (*a*), σ=330 MPa (*b*).

Creep curves for Ni_3Ge single crystals with both orientations [$\bar{2}34$] and [$\bar{1}22$] are similar. They demonstrate normal behaviour, i.e. the creep rate increases with increasing temperature and does not show anomaly at all study regimes. Very weak dependence of creep processes on the temperature has been revealed.

Creep rate

The creep curves at varios stresses and temperatures (Fig. 2 a and 3) were used for measuring the steady-state creep rate. Fig. 2 b and 4 show the creep stages for the investigated crystal and very low values of the creep rate. From these figures it is noticed that temperature influence on the creep rate practically is lacking. The resulting numerical

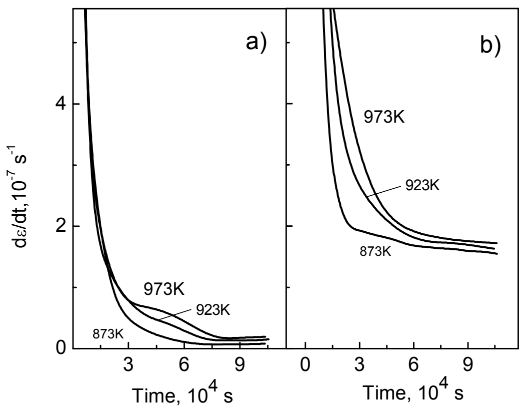


Fig. 4: Time dependence of the creep rate for Ni_3Ge single crystals at different test temperatures, the compressive-strain axis [$\bar{1}22$], the applied stress σ=230 MPa (*a*), σ=330 MPa (*b*)

Stress σ, MPa	Deformation axis				
	[$\bar{1}22$]			[$\bar{2}34$]	
	dε/dt, s^{-1}			*dε/dt*, s^{-1}	
	873 K	923 K	973 K	773 K	973 K
330	$1{,}9\cdot10^{-7}$	$2{,}13\cdot10^{-7}$	$2{,}14\cdot10^{-7}$	-	-
230	$2{,}6\cdot10^{-8}$	$2{,}7\cdot10^{-8}$	$2{,}9\cdot10^{-8}$	$3\cdot10^{-8}$	$5\cdot10^{-8}$

Table 2: The steady-state creep rates, s^{-1}

values of the steady-state creep rates are presented in Table 2.

EVALUATION OF THE RESULTS

These experiments showed that the creep curves for the Ni_3Ge single crystal with [$\bar{2}34$] and [$\bar{1}22$] orientations deformation axes displaying cubic (001)[$1\bar{1}0$] slip have one type of the creep curves. The observed dependences are two-stage curves at high temperatures. The creep curves for Ni_3Ge in the examined time interval generally exhibited the primary creep stage, where creep rate decreases with strain or time, and the secondary (steady-state) creep stage with a constant creep rate. These curves are characterized by a primary-creep rate as low as ~10^{-8}÷10^{-7} s^{-1}. Neither "inverse (sigmoidal) creep" nor ternary stage was detected. This is the fact that differs the creep curves behaviour of the Ni_3Ge alloy with [$\bar{2}34$] and [$\bar{1}22$] orientations from the creep curves of the crystals orientated along direction [001] [8] and [$\bar{1}39$] [9]. The last mentioned crystals demonstrate high temperature "inverse creep".

In regards to the steady-state creep rates, it should be noted that temperature dependence of the creep rate for Ni_3Ge single crystals is practically unavailable (Fig. 5). However, the

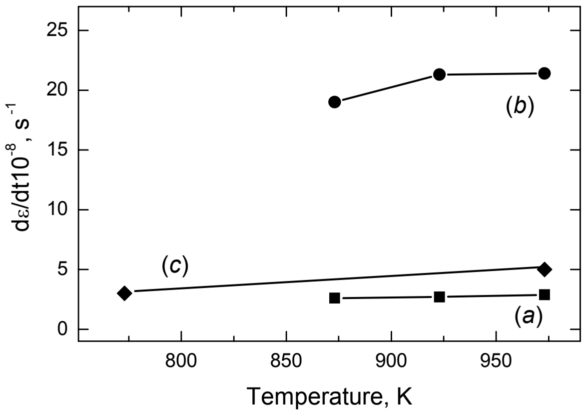


Fig. 5: Temperature dependence of the creep rate for Ni_3Ge single crystals at different stress levels, the compressive-strain axis [$\bar{1}22$], the applied stress σ=230 MPa (*a*), σ=330 MPa (*b*), the compressive-strain axis [$\bar{2}34$], the applied stress σ=230 MPa (*c*)

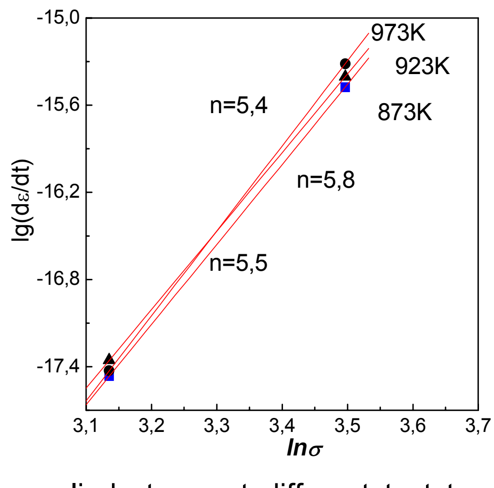


Fig. 6: Creep rate versus applied stress at different test temperatures for Ni_3Ge single crystals (the compressive-strain axis [$\bar{1}22$])

effect of strain on the steady-state creep rates is essential at the test temperatures.

Assuming that relationship between the steady-state strain-rate and stress

$$\frac{d\varepsilon}{dt} = K_2 \sigma^n ,$$

where σ is applied stress, ε is strain, K is constant, and n is stress exponent, the stress exponent n is determined from the analysis of the relation for the power law. When plotted in the coordinates $\ln(d\varepsilon/dt)$ versus $\ln\sigma$, the relation demonstrates a linear dependence (Fig. 6).

T,K	σ ,МПа	n	ln$K$
873	230 330	5,5	-122,3 -122,6
923	230 330	5,8	-128,1 -128,4
973	230 330	5,4	-120,4 -120,6

Table 3: Creep parameters for Ni_3Ge orientation [$\bar{1}22$]

The slope of these curves gave values of the stress exponent *n*. The stress exponent and the constant *K* for orientation [$\bar{1}22$] are shown in Table 3. This orientation is defined by high values, *n.* The value is above 5 and it is predominantly correspond to dislocation climb. The activation energy of creep for orientation [$\bar{1}22$] and [$\bar{2}34$] has been calculated. The values of the activation energy for creep of the Ni_3Ge single crystal with the orientation [$\bar{2}34$] and

Orientation	[$\bar{1}22$]		[$\bar{2}34$]
Stress, MPa	230	330	230
Q, kJ/mol	7,66±1,6	5,33±3,5	15,9

Table 4: The activation energy of creep for orientation [$\bar{1}22$] and [$\bar{2}34$]

[$\bar{1}22$] ranged from 5 to 16 kJ/mol and are presented in Table 4.

SUMMARY AND CONCLUSIONS

The study of creep deformation of the Ni_3Ge single crystals with [$\bar{2}34$] and [$\bar{1}22$] orientations at temperatures above the peak temperature Tp demonstrating cubic slip, reveal peculiar properties:

1. Two-stage creep curves without “inverse (sigmoidal) creep” occurred in this case. It should be noted that the traditional opinion is that the “inverse creep” is caused by cubic slip [1-5]; however, the low creep rates, the absence of the “inverse creep” call some doubt about this statement.

2. It is defined that the change in the orientation of the deformation axis leading to the cubic slip causes the increase in the resistance of the creep in the Ni_3Ge single crystals. Creep curves are characterized by a creep rate as low as ~10^{-8} – 10^{-7} s^{-1} in contrast to the values of creep rates for orientation axes [001], [$\bar{1}$39] ranged from 10^{-8} to 10^{-4} s^{-1}.

3. The type and stages of the creep curves were found not only temperature dependent, but also determined by the applied stress and the axis orientation.

4. The Ni_3Ge single crystals of the considered orientations have extraordinary stability of the steady-state creep rates to changing temperature unlike the orientation axes [001], [$\bar{1}$39], where octahedral (111)[1 0 $\bar{1}$] slip takes place.

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