PRE-MARTENSITIC PHENOMENA, MARTENSITIC TRANSFORMATION AND STRAIN VARIATION IN QUENCHED NI-RICH NiTi ALLOY

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ABSTRACT
The NiTi-based alloy may undergo the martensitic transformation during holding at constant temperatures within or outside the temperature range of the athermal martensitic transformation. It was assumed that this phenomenon was caused by the variation in the strain nanodomains structures in pre-martensitic temperature range that led to a decrease in elastic energy and change in the thermodynamic equilibrium that made possible the realization of the martensitic transformation at constant temperature. Moreover, the formation of the strain nanodomains and martensitic transformation should be accompanied by the strain variation on cooling and heating under a stress. The relation between the pre-martensitic phenomena, the isothermal martensitic transformation and strain variation in Ni-rich NiTi alloy has not been found and it is the aim of the present work. The pre-martensitic phenomenon and martensitic transformation was studied by resistivity measurement and differential scanning calorimetry on cooling and heating in a temperature range of 100 to -100 °C with different cooling/heating rate. The strain variation was measured on cooling and heating under a constant stress of 50 to 300 MPa in a temperature range of the pre-martensitic state and phase transformation. The results obtained show that the formation of the strain nanodomains is accompanied by the resistivity variation without any heat effects on calorimetric curve. A variation on cooling/heating rate influences the temperature ranges of the pre-martensitic states and transformation temperatures. The isothermal holding of the alloy in pre-martensitic temperature range leads to the formation of the martensitic phase. The strain variation on cooling and heating depends on the cooling/heating rate and the less the rate the larger the strain variation and the larger the plastic strain.

KEYWORDS: NiTi, MARTENSITIC TRANSFORMATION, ISOTHERMAL TRANSITION, STRAIN NANO-DOMAINS.

INTRODUCTION
Last decades it was found that the thermoelastic martensitic transformation might be observed in Ni-Ti based alloys during isothermal holding at temperatures T>M or T<M. [Kustov, 2012; Fukuda, 2013; Ji, 2015]. This opens a good opportunity for application of NiTi alloys in a limited temperature range. However, nature and the kinetics of this transformation as well as strain variation in the Ni-Ti alloys undergoing the isothermal transformation have not been studied. In [Resnina, 2016] it was assumed that the isothermal transformation might be induced by a variation in structure of strain nanodomains that appeared in pre-martensitic temperature range and it might be accompanying by the additional strain variation. Thus, the aim of the present work to study the relation between pre-martensitic phenomenon, isothermal transformation and strain variation in Ni-rich NiTi alloy.

MATERIALS AND METHODS
The Ni51Ti49 alloy was quenched from 850°C for 20 min to water to avoid the formation of precipitates. After heat treatment, the sample was subjected to thermal cycling to stabilize the temperatures of the martensitic transformation. In the 100th thermal cycle, the sample underwent the B2 →B19′ martensitic transformations on continuous cooling and heating at temperatures Ms = -43°C, Mf = -63°C, Astart = -24°C and Aend = -9°C.
To study the martensitic transformation during holding at a constant temperature and to estimate the volume fraction of the isothermally induced martensite the differential scanning calorimetry and the procedure described in [Resnina, 2016] was used.
To study the pre-martensitic phenomenon the resistivity variation was measured on cooling and heating of the Ni51Ti49 alloy in a temperature range of 100 to -100 °C with a cooling/heating range of 10 °C/min.
To study the strain variation, the sample was cooled and heated under a constant stress of 50 - 300 MPa in a temperature range of 100 to -100 °C with different cooling/heating rate from 1 to 10 °C/min.

RESULTS AND DISCUSSION
It was found that the kinetics of the isothermal martensitic transformation in Ni51Ti49 alloy depended on the position of the holding temperature with respect to the temperature range of the athermal forward martensitic transformation (Fig. 1). If the sample was kept at temperatures of Mf<T<Ms+4°C, then the volume fraction of the martensite that formed during isothermal holding (Φiso) increased sharply during first ten minutes and then the
transformation rate decreased to zero (Fig. 1a). An increase in holding temperature from \(M_s + 3^\circ C\) to \(M_s + 6^\circ C\) resulted in a decrease in transformation rate. At \(T < M_s\) (Fig. 1b) \(\Phi_{iso}\) value increased sharply for several minutes up to saturation despite the holding temperature. It was found that the saturation value depended on the holding temperature and that the maximum volume fraction of the isothermally martensite of 45 % was formed during the holding at \(T^* = M_s\).

An influence of the cooling/heating rate on the strain variation may be attributed to isothermal martensite appeared in the sample simultaneously with athermal martensite on cooling with a low rate. It results in an increase in reversible strain as well as total strain variation on cooling and heating. Moreover, a formation of the isothermal martensite is accompanied by the plastic strain that leads to the observation of the irreversible strain in the sample after heating.

**CONCLUSION**

Therefore, the results of the study may be summarized as following:

1. The variation in the volume fraction of the martensite that appeared during isothermal holding of quenched Ni\(_{51}\)Ti\(_{49}\) alloy was found at temperatures \(T^* > M_s\) and \(T^* < M_s\).
2. Isothermal martensitic transformation occurs on holding at temperatures of \(T^* > M_s\) that belong to a temperature range of the pre-martensitic phenomenon.
3. Maximum value of the isothermal martensite of 45 % appeared during holding at \(T^* = M_s\).
4. A decrease in cooling/heating rate from 10 °C/min to 1 °C/min influences the strain variation under a stress due to isothermal martensite appears simultaneously to the athermal martensite.

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**REFERENCES**


