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Strain variation in the $Ti_{40,7}Hf_{9,5}Ni_{41,8}Cu_8$ alloy during isothermal martensitic transformation under a constant stress

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Abstract. Strain variation on holding under a constant stress was studied in the $Ti_{40,7}Hf_{9,5}Ni_{41,8}Cu_8$ alloy. It was found, that on holding under stress, the isothermal strain rose up to saturation, which value depended on holding temperature and stress. It was found that the dependencies of the isothermal strain on the holding temperature and stress were non-monotonic. This allowed to find the optimal value of stress and time at which the isothermal strain attained the maximum value of 3.2 %. It was found that the maximum isothermal strain in the $Ti_{40,7}Hf_{9,5}Ni_{41,8}Cu_8$ alloy was less than in the $Ti_{40,7}Hf_{9,5}Ni_{44,8}Cu_5$ alloy.

1. Introduction

Thermoelastic martensitic transformations in NiTi-based shape memory alloys were believed to be characterized by athermal kinetics hence, the phase transformation could not occur during isothermal holding [1,2]. However, recently it was shown, that in NiTi-based alloys with substitutional defects, the martensite phase might appear during holding at constant temperature close to M_s [3-6]. For instance, the isothermal martensitic transformation was found in the $Ti_{40,7}Hf_{9,5}Ni_{44,8}Cu_5$ alloy, where Hf and Cu atoms substituted the Ti and Ni atoms and acted as substitutional defects. The kinetics of this process was well studied and it was shown, that during isothermal holding, the martensite volume fraction increased up to saturation, which value depended on holding temperature and chemical composition of the alloy [6,7]. Moreover, in [8,9] it was shown, that the forward martensitic transformation during isothermal holding under a stress was accompanied by recoverable strain variation.

The volume fraction of the martensite that appeared on isothermal holding without stress depended on the chemical composition of the alloys. Thus, one may assume that the strain variation induced by the isothermal transformation on holding under a stress may be sensitive to the chemical composition of the alloy. To verify this assumption, the strain variation during isothermal holding of the $Ti_{40,7}Hf_{9,5}Ni_{41,8}Cu_8$ alloy under a constant stress was studied and compared to the results found previously in the $Ti_{40,7}Hf_{9,5}Ni_{44,8}Cu_5$ alloy.

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2. Materials and methods

Amorphous $Ti_{40,7}Hf_{9,5}Ni_{41,8}Cu_8$ thin ribbon with a size of 15 × 1,6 × 0,04 mm was subjected to crystallization during isothermal holding at 470 °C for 30 min. The crystallized alloy underwent the B2↔B19′ transformation at temperatures of M_s = -8 °C, M_f = -14 °C, A_s = 39 °C, A_f = 48 °C. Mechanical experiments were carried out in the tensile mode using Lloyd 30K Plus testing machine, equipped with thermal chamber and video extensometer. To study the isothermal strain variation, the sample was cooled under a constant stress to holding temperature, held for 60 minutes and then heated through a temperature range of the reverse transformation (see details in [8,9]). Figure 1 demonstrates the typical strain and temperature variation on cooling, holding and heating under a stress. It is seen, that strain increases on cooling under a stress that is typical for NiTi-based alloys and caused by the formation of oriented martensite [1]. However, an additional strain variation is observed on holding under the same stress. On heating strain accumulated on cooling and holding under a stress completely recovers due to the reverse transformation. A_s complete strain recovery occurs on heating hence, the strain variation on cooling and holding is caused by the formation of oriented martensite. The strain variation on holding was studied at various holding temperatures close to M_s and under a different stress from a range of 160 MPa ÷ 400 MPa.

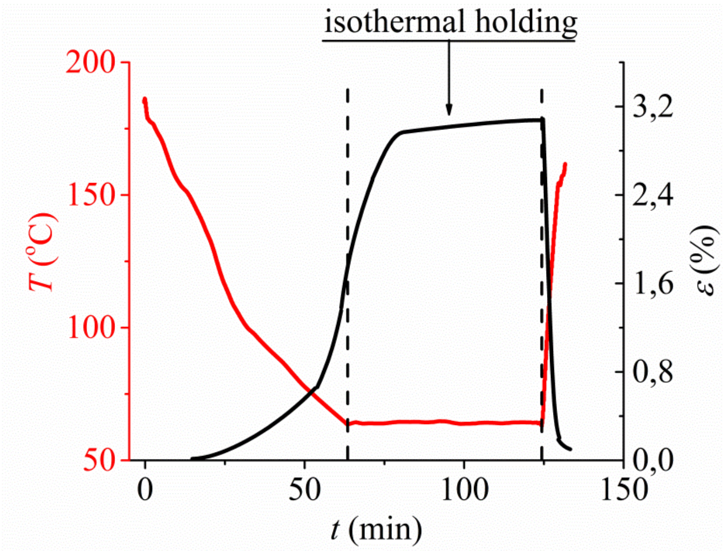

Figure 1. Temperature (red curve) and strain (black curve) variation on time during cooling, isothermal holding and heating of the $Ti_{40,7}Hf_{9,5}Ni_{41,8}Cu_8$ alloy under a stress of 400 MPa.

3. Results and discussion

Figure 2a presents the strain variation during holding at a temperature close to M_s under various constant stress. It is seen that strain increased to saturation, which value depended on stress and the maximum isothermal strain variation was found on holding under a stress of 240 MPa. Figure 2b shows the dependences of the isothermal strain variation for 60 minutes ε_{iso}^{60} on ΔT value which was equal to difference between the start temperature of the forward martensitic transformation under a stress M_s^{σ} (38 °C at 160 MPa, 48 °C at 240 MPa and 83 °C at 400 MPa) and holding temperature T^*. It can be seen that these dependences were non-monotonic and the maximum was observed at ΔT = -6±1 °C for all curves. The value of maximum isothermal stain depended on the stress and the largest value of 3,2 % was found on holding under 240 MPa.

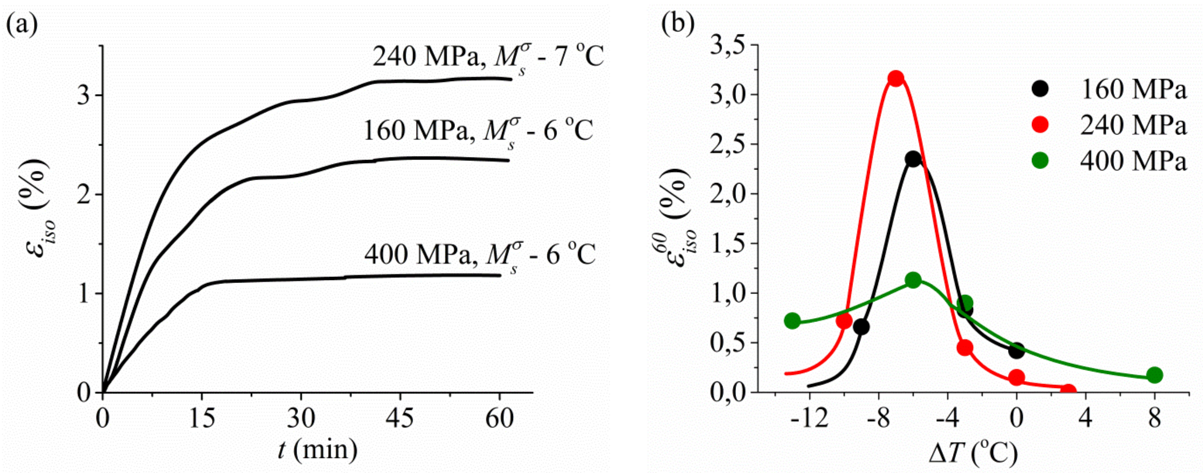

Figure 2. Strain variation during isothermal holding under various stress (a) and the dependences of isothermal strain variation for 60 min on ΔT under different stress (b).

Results found in the present work for the $Ti_{40,7}Hf_{9,5}Ni_{41,8}Cu_8$ alloy were compared with data obtained previously for the $Ti_{40,7}Hf_{9,5}Ni_{44,8}Cu_5$ alloy in [9]. In both alloys, holding under a stress at a temperature belonging to a temperature range of the forward martensitic transformation was accompanied by the isothermal strain variation that was completely recoverable on subsequent heating. The dependences of the isothermal strain on the position of the holding temperature compared to the M_s^σ temperature or on the stress were non-monotonic and the optimal regime (stress and holding duration) could be found for each alloy. The maximum (ε_{iso}^{max}) value was observed on holding at various stress in the alloys with the different Cu concentration (Figure 3). In the $Ti_{40,7}Hf_{9,5}Ni_{44,8}Cu_5$ alloy, the maximum isothermal strain was equal to 3,5 % and found on holding under 160 MPa whereas, ε_{iso}^{max} was equal to 3,2 % and observed on holding under 240 MPa in the $Ti_{40,7}Hf_{9,5}Ni_{41,8}Cu_8$ alloy.

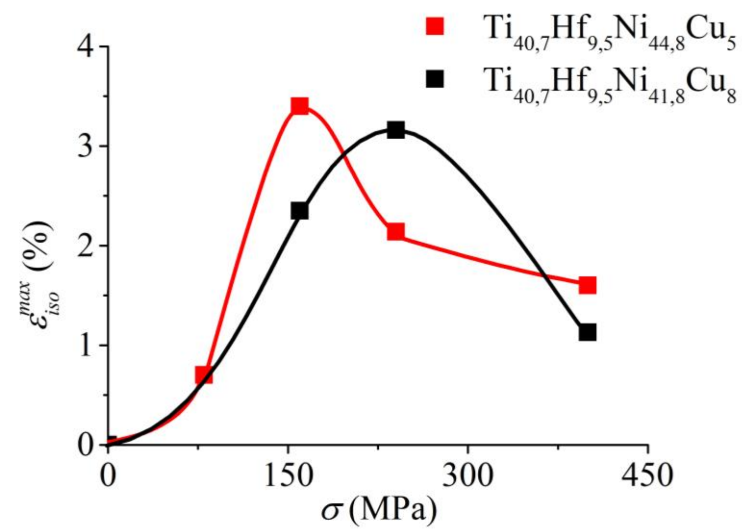

Figure 3. Dependence of the maximum isothermal strain on stress acted on holding stress.

Therefore, the observation of the strain variation on holding under a stress in the Ti-Hf-Ni-Cu alloys with various concentration of Cu and Ni atoms shows that this phenomenon is common feature of the alloys undergoing the isothermal martensitic transformations. All strain accumulated on holding

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completely recovers on subsequent heating hence, this strain variation is caused by the isothermal formation of martensitic under a constant stress. The variation in Ni/Cu ratio in $Ti_{40,7}Hf_{9,5}Ni_{49,8-x}Cu_x$ alloys influences the stress at which the maximum isothermal strain variation is observed. The variation in the Cu concentration slightly decreases the maximum isothermal strain from 3,5 % in the $Ti_{40,7}Hf_{9,5}Ni_{44,8}Cu_5$ alloy to 3,2 % in the $Ti_{40,7}Hf_{9,5}Ni_{41,8}Cu_8$ alloy however, to determine the influence of the alloy composition of the isothermal strain it is necessary to study the isothermal strain variation in the alloys with Cu concentration of 10 and more that will be carried out in future.

4. Conclusions

- A holding of the $Ti_{40,7}Hf_{9,5}Ni_{41,8}Cu_8$ alloy under a stress at temperatures belonging to the temperature range of the forward martensitic transformation was accompanied by the strain variation which was completely recovered on subsequent heating.
- The dependences of the isothermal strain on holding temperature or stress were non-monotonical and optimal regimes of holding can be found.
- The maximum isothermal strain was found on holding of $Ti_{40,7}Hf_{9,5}Ni_{41,8}Cu_8$ alloy under a stress of 240 MPa and this value was equal to 3,2 % that was less than in the $Ti_{40,7}Hf_{9,5}Ni_{44,8}Cu_5$ alloy.

Acknowledgment
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