SHAPE MEMORY EFFECT PARAMETERS IN TINI-BASED ALLOYS WITH SILVER

G.A. Baigonakova, E.S. Marchenko, D.V. Barashkova

Scientific Supervisor: Prof., Dr. V.E. Gunther

Tomsk State University, Russia, Tomsk, Lenin str., 36, 634050

E-mail: gat27@mail.ru

ПАРАМЕТРЫ ЭФФЕКТА ПАМЯТИ ФОРМЫ В СПЛАВАХ НА ОСНОВЕ TINI С СЕРЕБРОМ

Г.А. Байгонакова, Е.С. Марченко, Д.В. Барашкова

Научный руководитель: профессор, д.т.н. В.Э. Гюнтер

Томский государственный университет,

Россия, г. Томск, пр. Ленина, 36, 634050

E-mail: gat27@mail.ru

Аннотация. *Статья представляет исследования влияния добавки серебра с разной концентрацией до 1,5 ат.% на сплавы на основе TiNi. Построены температурные зависимости накопления и возврата деформации при многократном эффекте памяти формы (ЭПФ) сплавов (TiNiMoFe)Ag и определены параметры ЭПФ (температуры начала и конца накопления и возврата деформации, остаточная и обратимая деформации, ширина петли гистерезиса). Показано, что увеличение концентрации серебра приводит к росту ширины петли гистерезиса и величины обратимой деформации. Изменение состава в B2 структуре приводит к смещению характеристических температур превращения исследуемых сплавов.*

Introduction. It is known that the TiNi-based alloys are a promising and attractive material for biomedical applications among shape memory alloys. Many characteristics of alloys can be improved by adding alloying elements. The biocompatible TiNiMoFe alloy (TN-10 brand) has been chosen as a basis due to its unique hysteresis properties presents a high scientific interest [1]. From the biomedicine point of view, silver is a promising alloying element, since it is known for its antibacterial properties, which is related to the release Ag+ ions from pure silver phases [2]. In addition, TiNiAg alloys show good biocompatibility and corrosion resistance comparable to binary TiNi alloys. In [3] the effect of silver adding on hysteresis and physico-mechanical properties is considered. Although the biocompatible TN-10 alloy provides excellent properties, the antibacterial effect would significantly expand the range of its biomedical applications. Therefore, the purpose of this work is to study the effect of an addition of different silver concentrations on the parameters of the multiple shape memory effect in TiNiMoFe alloys.

Materials and Methods. TiNiMoFeAg alloys were prepared in an induction furnace in an atmosphere of inert argon gas by remelting sponge Ti and Ni plates with the addition of the Mo, Fe and Ag alloying elements. The alloying scheme: $Ti_{50}Ni_{49.5-X}Mo_{0.3}Fe_{0.2}Ag_X$ (X = 0, 0.1, 0.2, 0.5, 1 at.%). Specimens (50 × 1 × 1 mm in size) were spark cut by electric-discharge wire-cut from the produced ingots. The shape memory parameters were studied in conditions of tension under a constant load of 2 kg.

Results. Fig. 1 shows the temperature dependences of strain accumulation and recovery at multiple SME ε(T) of (TiNiMoFe)Ag with different Ag concentration under a constant load. In all the investigated alloys the martensitic transformation (MT) with a sequence B2→R→B19' is realized, where the MT products are the rhombohedral R- and monoclinic B19'-phases [4, 5]. The complete transformation cycle is characterized by the temperatures M'_S, M'_f, A'_S, A'_f. At $T < M'_f$ the martensite is stable, and the stable phase at $T > A'_f$ is austenite. For the temperature values $M'_S < T < A'_S$ both phases are stable.

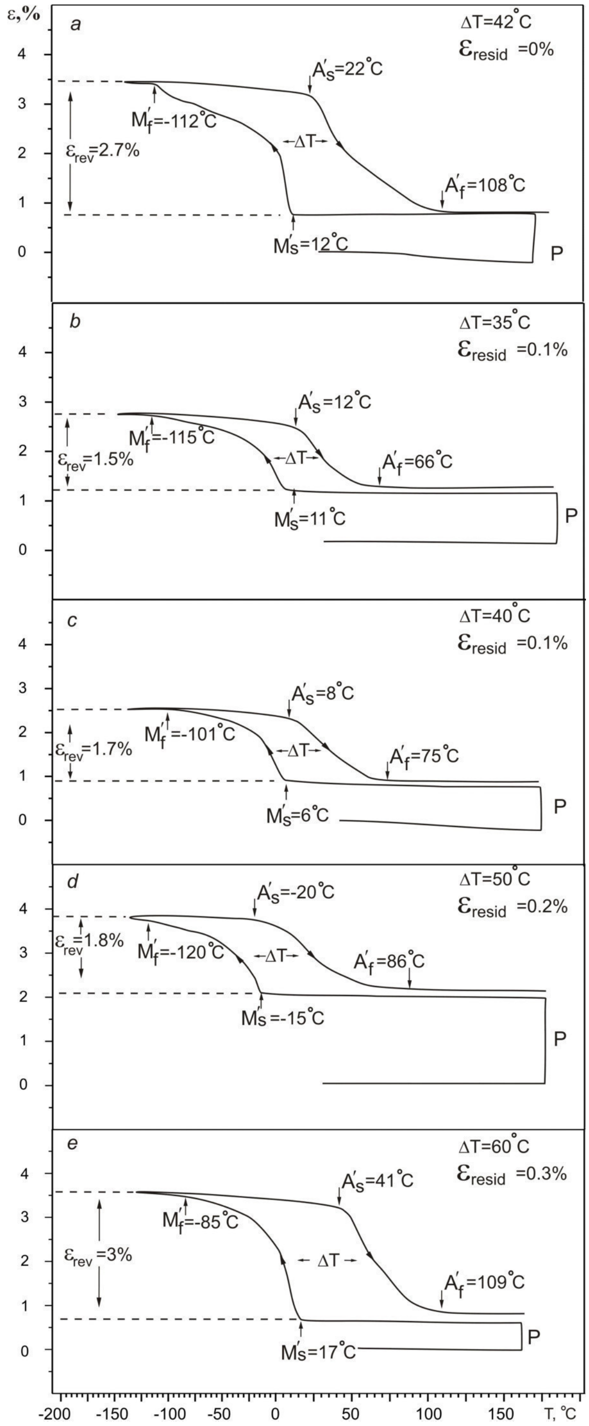

Fig. 1. Temperature dependences of strain accumulation and recovery at multiple SME ε(T) of (TiNiMoFe)Ag in the initial state without Ag (a) and with Ag concentration: (b) – 0.1 at.%, (c) – 0.2 at.%, (d) – 0.2 at.%, (d) – 0.5 at.%, (e) – 1 at.%, where ε_{rev} and ε_{resid} are the reversible and residual strains, ΔT is the hysteresis loop width; M'_S, and M'_f – start and finish temperatures of strain accumulation, A'_S, and A'_f – start and finish temperatures of strain recovery

The experimental results show that doping with silver to 0.5 at.% leads to a decrease in the MT temperatures compared to the initial alloy, while the addition of 1 at. % Ag increases the temperatures. The change in the composition of TiNi in the homogeneity region connected with deposition of secondary phase's particles affects the MT temperatures displacement. With an increase in the Ag content from 0.1 to 1 at. % the reversible strain increases in the alloys and reaches ≈ 3%. The alloys have the residual strain ε_{resid}, but in the alloys with 1 at.% Ag it is maximal. ε_{resid} is the result of plastic strain, which leads to a decrease in the mobility of the interphase boundary. The plastic component of strain also causes a wider hysteresis width. The width of the hysteresis loop ΔT increases with increasing concentration of silver in the alloy. This value corresponds to the amount of energy dissipated at full MT cycle and it is defined by the sum of contribution of "chemical" and "non-chemical" components of a dissipative driving force [1]:

$$\Delta G = G_D^{A\to M} + G_D^{M\to A} = (\Delta G_{хим} + \Delta G_{нехим}) = \frac{H}{T_0}\left(\frac{A_S + A_f}{2} - \frac{M_S + M_f}{2}\right) + (V^M + V^A)p \quad (1).$$

where ΔG – the Gibbs dissipative driving force; the first term of the equation is a "chemical" component contribution of the driving force (H – absolute value of the latent heat of MT, T_0 – the temperature of the chemical phase equilibrium); V^M and V^A – the volumes of low-temperature and high-temperature phases; p is the "non-chemical" contribution which occurs due to the energy dissipation in the process of formation and motion of interphase boundaries during the MT (by convention, this contribution is called "friction").

Temperature dependences of strain accumulation and recovery at multiple SME ε(T) of (TiNiMoFe)Ag show that alloys with 0.1, 0.2 and 0.5 at.% Ag exhibit the more pronounced hysteresis slope as compared with the alloys with 0 and 1 at.% Ag. This is explained by an increase in the nonchemical contribution p to the total dissipative energy of the MT and the decrease in the total material volume (V^M + V^A) participating in the martensite transformation according to equation (1).

Shape memory effect parameters as well as other properties of TiNi-based alloys are sensitive to the composition change due to the silver addition. It was shown that a growth in the silver concentration led to an increase in the hysteresis loop width and the reversible strain value. The change in B2 structure composition led to a shift in the characteristic transformation temperatures of the investigated alloys. The alloy with 1 at.% Ag showed the maximum values of transformation temperatures, residual strain ε_{resid}, reversible strain ε_{rev} and hysteresis loop width ΔT.

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