Contents lists available at ScienceDirect





Materials Characterization

journal homepage: www.elsevier.com/locate/matchar

Study of the microstructure evolution of heat treated Ti-rich NiTi shape memory alloy



Ghazal Tadayyon ^a, Mohammad Mazinani ^a, Yina Guo ^b, Seyed Mojtaba Zebarjad ^{c,*}, Syed A.M. Tofail ^b, Manus J.P. Biggs ^d

^a Department of Material Science and Engineering, Engineering Faculty, Ferdowsi University of Mashhad, P.O. Box 91775-1111, Azadi Square, Mashhad, Iran

^b Materials and Surface Science Institute, University of Limerick, Castletroy, Co. Limerick, Ireland

^c Department of Material Science and Engineering, Engineering Faculty, Shiraz University, Namazi Square, Shiraz, Iran

^c Network of Excellence for Functional Biomaterials, National University of Ireland, Biosciences Building, Newcastle Road, Dangan, Galway, Ireland

ARTICLE INFO

Article history: Received 31 August 2015 Accepted 19 November 2015 Available online 1 December 2015

Keywords: Nickel-titanium shape memory alloy Microstructural evolution Annealing Solution treatment

ABSTRACT

Martensitic evolution in Ti-rich NiTi alloy, Ti50.5Ni49.5, has been investigated as a function of annealing, solution treatment and a combination thereof and a detailed electron microscopic investigation carried out. Self-accommodated martensite plates resulted in all heat treated samples. Martensitic <011> type II twins, which are common in NiTi shape memory alloys, was found in both as-received and heat-treated samples. Solution treated samples, additionally, showed {11-1} type I twinning was also found in samples that have been annealed after solution-treatment. Another common feature of the microstructure in both as-received and heat treated samples is the formation of Ti₂Ni precipitates. The size, number and dispersions of these precipitates can be controlled by resorting to a suitable heat treatment e.g. solution treatment.

© 2015 Elsevier Inc. All rights reserved.

1. Introduction

NiTi alloys belong to a unique class of multifunctional materials, which exhibit shape memory effects (SME) and superelasticity (SE) [18]; (Lagoudas [11]). SME and SE respectively allow NiTi to exhibit large induced internal forces due to a change in temperature and high recoverable strains. These extraordinary properties in NiTi originate from a reversible crystallographic transformation between a parent phase (austenite) and a product phase (martensite). The transformation can be driven either by changing temperatures (Thermally Induced Martensite, TIM), or by applying strains (Stress Induced Martensite, SIM) (Lagoudas [11]). These unique features of NiTi alloys have found applications in components and devices in aerospace engineering, medical devices, actuators and energy harvesting ([3,6,7,14,15,20].

Martensitic transformation is the crux of shape memory and pseudoelastic behaviors of NiTi and is greatly affected by the stoichiometry, thermal history and post processing heat treatments. Equiatomic NiTi, generally known as NiTiNOL, possesses a 50:50 atomic percentage (at.%) between Ni and Ti, and is generally austenitic at room temperature. A small deviation from the equiatomic proportion between Ni and Ti, especially in Ni, can drastically affect transformation behaviors of NiTi. For instance, a difference of just 0.1 at.% of Nickel can change the transformation temperatures by 20 °C or even more [1]. A Ti-rich composition, on the other hand, remains generally martensitic at room temperature as the

temperatures for martensitic transformations such as Martensite start (Ms), Austenite start (As) and Austenite finish (Af) temperatures usually lie at relatively higher temperatures than those for Ni-rich NiTi. For example, Af temperatures of Ti rich NiTi alloys typically lie above 70–100 °C, while the Af temperature of an equiatomic and Ni rich NiTi generally lies below 40 °C [16]. Thermomechanical processing, cold working and heat setting are known to cause precipitate formation, variation of local stoichiometry and microstructural variations affect martensitic transformation and overall SE and SME in NiTi [3].The final transformation behavior of NiTi alloy is thus tunable by controlling its starting chemistry (e.g. equiatomic, Ni-rich, Ti rich, binary, ternary, quaternary and so on), thermomechanical processing, and heat treatment.

Austenitic compositions of equiatomic and Ni-rich NiTi have been relatively more widely investigated in terms of microstructural impacts of heat treatment and thermomechanical processing ([22,27]. Information on the impact of heat treatment and microstructure evolution is relatively less available in the case of Ti-rich alloys, which the present article discusses.

In martensitic transformation of shape memory alloys, twinning plays a critical role. Twinning is a planar defect in crystals and occurs in shape memory alloys due to a reversible, primary lattice invariant shear [5]. Deformation twins can be classified into three types according to the rationality of twinning planes (K1 and K2) and shear directions (η 1 and η 2) [4]. Type I twin (K1 and η 2 are rational), Type II twin (K2 and η 1 are rational) and compound twin (K1, K2, η 1 and η 2 are all rational) [4]. According to Otsuka [19], <011> Type II twinning occurs in NiTi due to the lattice invariant shear. In polycrystalline NiTi

Corresponding author.
E-mail address: Mojtabazebarjad@shirazu.ac.ir (S.M. Zebarjad).



Fig. 1. DSC test for the as-received NiTi rod.

alloys, (111) Type I twinning, which is also a lattice invariant shear, can take place [17].

Crystallographic nature of such twinning is important in determining the effect of heat-treatment such as aging and solution treatments and calls for high resolution, electron microscopy analysis.

The region of great interest in a binary Ni-Ti phase diagram is the metastable NiTi phase that occurs between 50 and 60% of Ni by weight, which is surrounded by Ti_2Ni and $TiNi_3$ intermetallic compounds. This is the region where a single austenite phase converts into the martensitic phase [1]. Deviations of composition from the equiatomic proportion (50:50 Ni and Ti) lead to precipitation of second phases within the NiTi matrix. Precipitates change local strains and matrix compositions, which in turn, impact martensitic transformation temperatures and functional behaviors of the alloy [24].

Precipitates of Ti₂Ni phase are common in Ti-rich NiTi alloys. Semicoherent precipitates of Ti₂Ni within the matrix causes a misfit that is significantly relaxed [8]. The role of the GP zones and Ti₂Ni precipitates in the martensitic transformation was clarified based on their structural characteristics in the parent phase [13]. In a Ti-rich composition (50.2Ti-Ni (at.%)) [2], precipitation of Ti_2Ni and its effect on the microstructural evolution during processing of the alloy into a wire form showed that $Ti_2Ni/NiTi$ interfaces were mostly faceted and assist in nucleation of martensite. The formation of $TiNi_3$ precipitates may have deleterious effects due to its high hardness and makes the alloy difficult to process.

Here we report microstructural and crystallographic aspects of martensitic transformation behavior in Ti rich NiTi. We then investigate impact of heat treatment through microstructural studies of the precipitates formed in Ti-rich NiTi at various stages of heat treatment.

2. Experimental procedures

Annealed NiTi bars 8 mm in diameter with a nominal composition of Ni49.5Ti50.5 were purchased from Nitinol Device and Components (NDC) Inc. In this alloy, oxygen and carbon are present at slightly below 0.05 and 0.02%, respectively. According to DSC (Differential



Fig. 2. XRD patterns of Ni-50.5 at.%Ti, as-received and heat-treated samples.

Download English Version:

https://daneshyari.com/en/article/1570592

Download Persian Version:

https://daneshyari.com/article/1570592

Daneshyari.com