TEM investigation of microstructures in low-hysteresis $Ti_{50}Ni_{50-x}Pd_x$ alloys with special lattice parameters

R. Delville[1], D. Schryvers[1], Z. Zhang[2], S. Kasinathan[2], R.D. James[2]

1. Electron Microscopy for Materials Science (EMAT), University of Antwerp,
Groenenborgerlaan 171, B-2020 Antwerp, Belgium
2. Department of Aerospace Engineering and Mechanics, University of Minnesota,
Minneapolis, Minnesota 55455, USA

remi.delville@ua.ac.be

Keywords: shape-memory alloy, low hysteresis, twinning

NiTi is one of the most popular shape-memory alloys (SMA) in medical applications because of its biocompatibility and its remarkable properties that allow recoverable mechanical energy to be stored in a compact delivery system. Still, its undesirable fatigue properties exemplified by the occurrence of medical-device fracture, along with large temperature/stress hysteresis and the narrow temperature range of operation translate to a tight margin of error for engineering design of the devices.

A new theory on the origin of reversibility of phase transformations predicts the microstructures and explains the fundamental cause of large transformation hysteresis commonly shown by SMAs [1]. It predicts that the hysteresis can be drastically minimized by improving the geometric compatibility of the martensite and the austenite. This has been demonstrated [2] with alloys with special lattice parameters with a middle eigenvalue of their transformation matrix satisfying $\lambda_2=1$ [2,3,4]. Their hysteresis decreases as the middle eigenvalue gets closer to one.

The present work focuses on the TEM investigation of ternary $Ti_{50}Ni_{50-x}Pd_x$ alloys in which different amounts of Pd substitution on Ni lead to special ratios between the austenite and martensite lattice parameters. As the compatibility between the two phases increases, a change in the microstructure is observed. Away from the compatibility condition with $\lambda_2>1$, martensite plates contain fine internal twins (microtwins) which are the result of stress accommodation at the austenite-martensite habit plane. Electron diffraction shows that the fine twinning occurs along a (1-11) type I mode. Martensite plates are also found to be related to each other along a <2-11> type II twinning mode. Calculations derived from the Geometrically Non-Linear theory of Martensite (GNLTM) [1] predict the two observed twins along with a (011) compound twin. It can also be demonstrated theoretically that as $\lambda_2>1$, compound twins are forbidden. Conversely, as $\lambda_2<1$, type I/II twins are forbidden and only compound twins allowed.

As the content of Pd is decreased toward the compatibility condition, detwinning of the martensite is observed. When the compatibility condition is satisfied ($Ti_{50}Ni_{39}Pd_{11}$) the microstructure contains large plates of untwined martensite (figure 1). Internal microtwins have completely disappeared. Since the distortion is minimal, twins do not need to be fine. Random twinning is observed, contrasting with ordered stacks of twins observed with alloys away from the compatibility condition. Twinning seems to occur

S. Richter, A. Schwedt (Eds.): EMC 2008, Vol. 2: Materials Science, pp. 413–414,
DOI: 10.1007/978-3-540-85226-1_207, © Springer-Verlag Berlin Heidelberg 2008

along boundaries of martensite plates or as a result of nucleation variation. In addition to the (1-11) type I and <2-11> type II twins, (011) compound twins are also observed. This can be accounted to the fact that the sample sits at the limit condition $\lambda_2=1$, thus allowing the three type of twins to coexist in the sample due to local lattice parameters variation. An ongoing study of local variation of composition (EDS, EELS) or lattice parameters (CBED) is attempting to relate them to the type of twins.

In-situ study of the growth of martensite inside the austenite is made possible at the $Ti_{50}Ni_{40}Pd_{10}$ composition which contains nucleated martensite inside the austenite at room-temperature. Preliminary results show exact austenite-martensite habit planes with no traces of twinning. It agrees with the fact that $Ti_{50}Ni_{40}Pd_{10}$ is also very close to satisfying the compatibility condition. In-situ cooling will show how such a twinless martensite can grow along the habit plane and how the final martensite microstructure arises.

1. Ball, J. M., James R.D., Phil. Trans. R. Soc. Lond., (1992) A 338-339.
2. J. Cui et al., Nature Materials 5 (2006) 286-290.
3. K.A. Bywater, J.W. Christian, Phil. Mag. 25-26 (1972) 1249-1273.
4. W.J. Moberly, J.L. Proft, T.W. Duerig, R. Sinclair, Mat. Sci. For., 56-58 (1990) 605-610.
5. We kindly acknowledge the support from the Marie Curie Research Training Network MULTIMAT "Multi-scale modelling and characterization for phase transformations in advanced material" (MRTN-CT-2004-505226)

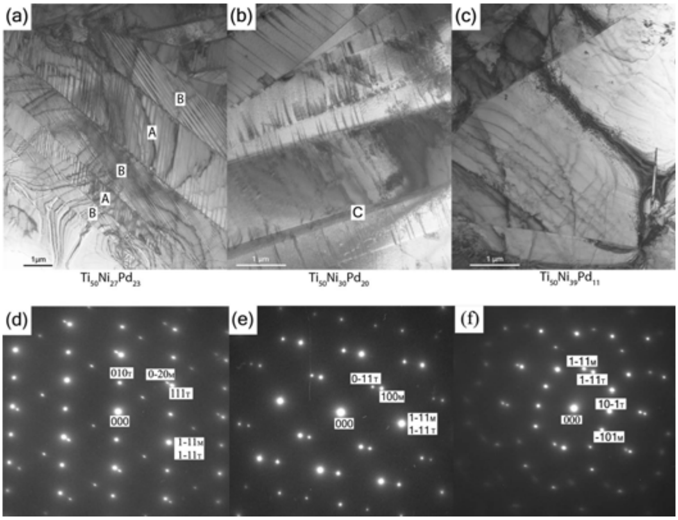

Figure 1. Change of microstructure with composition is shown in the bright field images (a)-(c). Fig. (a) shows internally twinned martensite plates, (b) shows the detwinning of the plates and (c) a twinless plate when the compatibility condition is satisfied. SAD patterns (d,e) correspond to plates A and B in (a), respectively, showing a (1-11) type I twinning. SAD pattern (f) was taken over the twin boundary C and shows a <2-11> type II twin.