REORIENTATION OF MARTENSITE

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ABSTRACT

Recent progress in understanding the reorientation of martensite variants during mechanical loading is reviewed. In this study, after a brief review of the elementary deformation mechanisms [e.g. Liu, 1999], an attempt is made to explain the effect of temperature and texture on the reorientation of martensite variants. To reach this goal, two martensitic $Ni_{50}Ti_{50}$ wires and sheets with similar grain sizes and transformation temperatures but different textures were investigated [Laplanche, 2017].

KEYWORDS: NITI; SHAPE MEMORY EFFECT; MARTENSITIC TRANSFORMATION; TEXTURE.

INTRODUCTION

This presentation focuses on one of the most thoroughly investigated shape memory alloys, NiTi, which are widely used in the medical sector. As shape memory properties strongly depend on crystallographic orientation [Miyazaki, 1984], the texture of polycrystalline NiTi alloys has attracted a lot of interest in the scientific community. It is currently well-documented that NiTi rolled sheets exhibit a strong $<011>_{B2}$ fiber texture parallel to the rolling direction whose amplitude depends on the rolling temperature [Inoue, 1996]. In contrast drawn wires after recrystallization show a strong $<111>_{B2}$ fiber texture parallel to the wire axis [Šittner, 2004].

At temperatures below M_f, NiTi alloys are fully martensitic and exhibit a self-accommodated microstructure. Upon mechanical loading, favorably oriented martensite variants grow at the expense of the others which can result in ~10% strain. After unloading, the deformation can be recovered on heating the shape memory alloy above A_f. During this heat treatment, all martensite variants transform to austenite and the material recovers its original shape prior to deformation (one way effect). Interestingly, it has been known for a long time that the apparent yield stress for the reorientation of martensite variants increases with decreasing temperature for $T < M_f$ [Saburi, 1989] but no efforts were done so far to model the effect of temperature on the reorientation of martensite variants.

In the present work, to study the effect of texture and temperature on reorientation of martensite variants, NiTi sheets and wires were tensile strained at temperatures ranging between -100°C and 60°C.

INFLUENCE OF TEXTURE AND TEMPERATURE ON THE REORIENTATION OF MARTENSITE VARIANTS

The stress-strain curves of the NiTi alloys are characterized by a stress-plateau (Fig. 1) which occurs concomitantly with the propagation of a Lüders band. The tensile tests were interrupted after the end of the stress-plateau. After unloading, the tensile specimens were heated to trigger the one way shape memory effect and the associated recoverable strains were measured, see dashed lines at the bottom of Fig. 1.

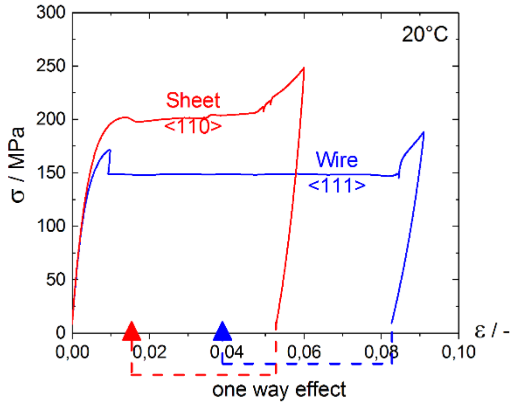

Figure 1: Comparison of tensile stress-strain curves and recoverable strains (dashed lines) obtained at 20 °C for NiTi wires and sheets.

A comparison between the mechanical data obtained for tensile specimens taken from wires and sheets revealed a strong effect of texture. The plateau stresses $\sigma_{plateau}$ of wires were found to be 25-33% lower (Fig. 2a) and their recoverable strains ε_{rec} were 30% higher than for sheets (Fig. 2b). However, the product of plateau stress and recoverable strain, which represents the external work per unit volume required for martensite variants reorientation is found to be independent of texture, see Fig. 2c. The tensile tests performed at different temperatures revealed that the recoverable strain is independent of temperature. In contrast, the plateau stress as well as the external work required to reorient martensite variants increase with decreasing temperature.

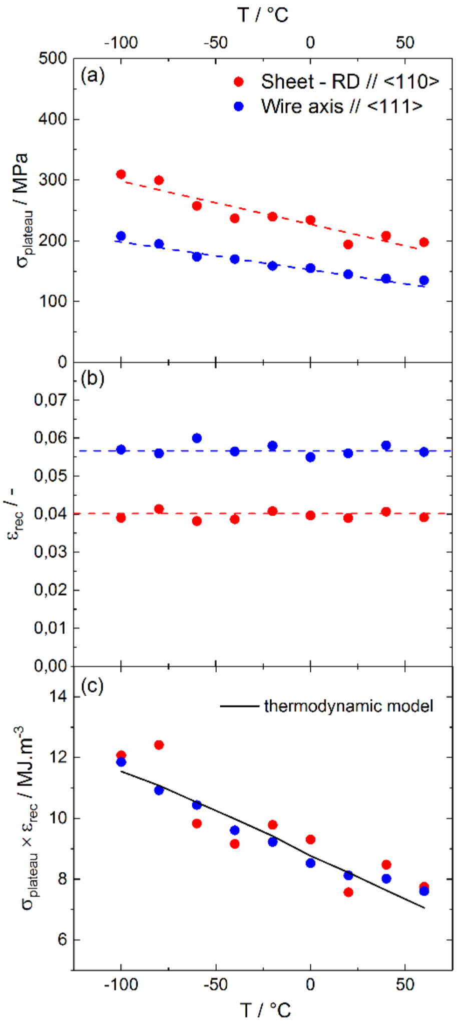

Figure 2: Influence of temperature on shape memory properties for NiTi wires and sheets. (a) plateau stress, (b) recoverable strains, and (c) products of plateau stresses and corresponding recoverable strains. The black line in (c) is calculated using a thermodynamic approach.

THERMODYNAMIC APPROACH

To rationalize the finding that the external work required to reorient martensite variants increases with decreasing temperature, we use a thermodynamic approach [Olson, 1986] involving the elastic strain energy associated with the growth of an ellipsoidal reoriented martensite variant. According to this model, the temperature dependence of the external work depends on two key parameters, namely, the shear modulus μ and the monoclinic angle β:

$$\sigma_{\text{plateau}}\varepsilon_{\text{rec}} = \left(\frac{\pi\,(2-\nu)}{4(1-\nu)}\right)\frac{t}{r}\,\mu\left(\beta-\frac{\pi}{2}\right)^2 \qquad (1),$$

where $\nu = 0.35$ is the Poisson's ratio of self-accommodated martensite, t and r are the semi-thickness and radius of the reoriented nucleus, respectively. Inserting the experimental temperature dependencies of μ [Prokoshkin, 2011] and β [Brill, 1991] which were reported in the literature into Eq. (1), we obtain the black line shown in Fig 2c which allows to rationalize the experimental data.

CONCLUSION

The decrease of the external work required to reorient the martensite variants with increasing temperature results from two factors: the shear modulus softens (major contribution: 60-70%) and the magnitude of the monoclinic angle decreases with increasing temperature (minor contribution 30-40%).

ACKNOWLEDGMENTS

The Alexander von Humboldt foundation and the german research association (DFG, FR 2675/2-1) are greatly acknowledged

REFERENCES

[Brill, 1991] T.M. Brill, S. Mittelbach, W. Assmus, M. Mullner, B. Luthi, Elastic properties of NiTi, J. Phys. Condens. Matter 3 (1991) 9621.

[Inoue, 1996] H. Inoue, N. Miwa, N. Inakazu, Texture and shape memory strain in TiNi alloy sheets, Acta Mater. 44 (1996) 4825.

[Laplanche, 2017] G. Laplanche, T. Birk, S. Schneider, J. Frenzel, G. Eggeler, Effect of temperature and texture on the reorientation of martensite variants in NiTi shape memory alloys, Acta Materialia 127 (2017) 143.

[Liu, 1999] G Y. Liu, Z.L. Xie, J. Van Humbeeck, L. Delaey, Effect of texture orientation on the martensite deformation of NiTi shape memory alloy sheet, Acta Mater. 47 (1999) 645.

[Miyazaki, 1984] S. Miyazaki, S. Kimura, K. Otsuka, Y. Suzuki, The habit plane and transformation strains associated with the martensitic transformation in Ti-Ni single crystals, Scripta Metallurgica 18 (1984) 883.

[Olson, 1986] G.B. Olson, M. Cohen, Dislocation Theory of Martensitic Transformations, In: Nabarro FRN, editor, Dislocations in Solids, vol. 7, Elsevier Science Publishers, 1986, p.297.

[Prokoshkin, 2011] S.D. Prokoshkin, A.V. Korotitskiy, V. Brailovski, K.E. Inaekyan, S.M. Dubinskiy, Crystal lattice of martensite and the reserve of recoverable strain of thermally and thermomechanically treated Ti-Ni shape-memory alloys, Phys. Met. Metallogr. 112 (2011) 170.

[Saburi, 1989] T. Saburi, T. Takagaki, S. Nenno, K. Koshino, Mechanical Behavior of Shape Memory Ti-Ni-Cu Alloys, MRS Int. Meet. Adv. Mater., vol. 9, Pittsburgh, 1989. p.147.

[Šittner, 2004] P. Šittner, P. Lukáš, V. Novák, M.R. Daymond, G.M. Swallowe, In situ neutron diffraction studies of martensitic transformations in NiTi polycrystals under tension and compression stress, Mater. Sci. Eng. A 378 (2004) 97