ANISOTROPIC SUPERELASTICITY OF TEXTURED Ti-Ni SHEET

P. THAMBURAJA, S. GAO, S. YI and L. ANAND

Abstract— **A recently developed crystal-mechanics-based constitutive model for polycrystalline shape-memory alloys (Thamburaja and Anand [1]) is shown to quantitatively predict the in-plane anisotropy of superelastic sheet Ti-Ni to reasonable accord.**

Keywords— **Phase transformations, Constitutive equations, Finite-elements, Mechanical testing.**

I. Introduction

POLYCRYSTALLINE Ti-Ni is the most widely used shape-memory material in industry. It is typically processed in the form of wires, bars and sheets. Superelastic Ti-Ni in sheet and ribbon form is used in actuation devices. For a given Ti-Ni sheet, experimental evidence has shown the superelastic behavior along different directions in the plane of the rolled sheets to be measurably anisotropic (eg. Saburi [2], Zhao et al. [3]). We have conducted our own superelastic experiments on Ti-Ni sheets, and the experimental results also show the in-plane anisotropic superelastic response. The purpose of this brief paper is to show that the recently developed crystal-mechanics-based constitutive model of Thamburaja and Anand [1] adequately captures the in-plane anisotropy.

II. EXPERIMENTAL PROGRAM

Superelastic Ti-Ni sheets were obtained from a commercial source. Tensile specimens were cut along different directions and tested, ranging from 0^o (rolling direction) to 90^o (transverse direction) at 10^o intervals. Superelastic tension experiments were conducted at room temperature ($\theta = 298\,\mathrm{K}$) under displacement control at very low strain rates to ensure isothermal testing conditions.

Experimental pole figure measurements of the initially-textured sheet were obtained using a Rigaku 200 X-ray diffraction machine. The {111}, {110} and {100} experimental pole figure is shown in figure 1(a). A numerical representation of the experimental pole figures using 420 discrete unweighted crystal orientations was obtained by using the computer program PoPLa [4]. The numerical representation of the experimental pole figures is shown in figure 1(b).

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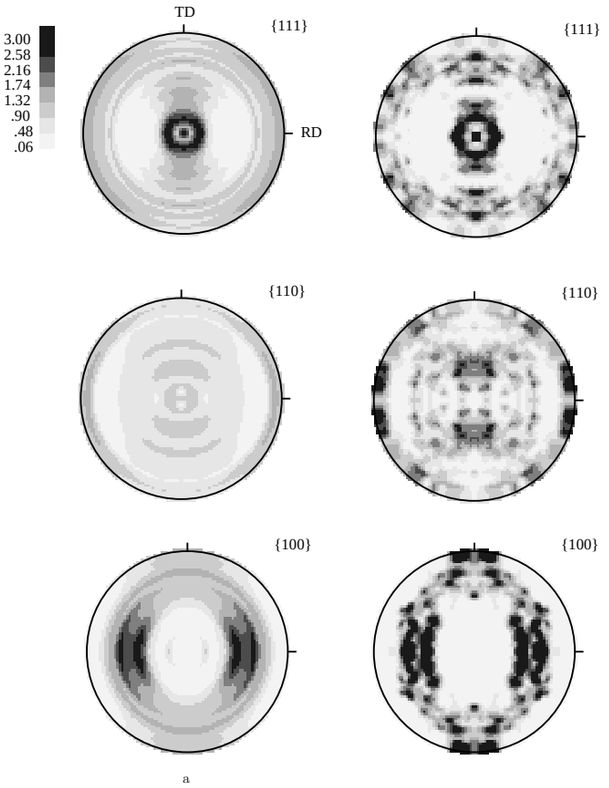

Fig. 1. (a) Experimentally-measured texture in the as-received Ti-Ni sheet, and (b) its numerical representation using 420 discrete unweighted crystal orientations.

III. FINITE-ELEMENT SIMULATIONS AND RESULTS

Thamburaja and Anand [1] have implemented their constitutive model in the ABAQUS/Explicit [5] finite-element program. The initial finite-element mesh used to model a representative volume element (RVE) of the polycrystalline material is shown in figure 2(a).

In our finite-element model of a polycrystal, each element represents a single crystal, and it is assigned a crystal orientation from the set of crystal orientations which approximate the initial crystallographic texture of the material shown in figure 1(b).

The material parameters in the constitutive model were calibrated to the tension experiment conducted along the rolling direction. The procedure to determine the material

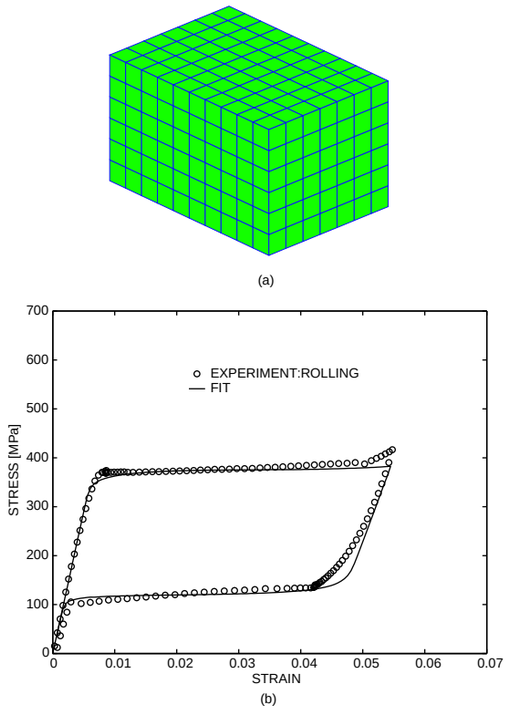

Fig. 2. (a) Undeformed mesh of 420 ABAQUS C3D8R elements used to represent a textured polycrystal aggregate. (b) Superelastic stress-strain curve in tension along the rolling direction. The experimental data from this test were used to estimate the constitutive parameters. The curve fit using the full finite-element model of the polycrystal is also shown.

parameters is outlined in Thamburaja and Anand [1]. The fit of the constitutive model to the tension experiment conducted along the rolling direction is shown in figure 2(b). The single-crystal material parameters used to obtain this fit are:

Elastic moduli for austenitic : $C^a_{11} = 130\,\text{GPa}, C^a_{12} = 98\,\text{GPa}, C^a_{44} = 22\,\text{GPa}$.

Elastic moduli for martensitic: $C^m_{11} = 65\,\text{GPa}, C^m_{12} = 49\,\text{GPa}, \; C^m_{44} = 11\,\text{GPa}$.

Transformation strain: $\gamma_T = 0.1308$.

Temperature dependence of driving force : $C(\theta - \theta_T) = 102\,\text{MPa}$ at $\theta = 298\,\text{K}$.

Critical driving force: $f_c = 6.9\,\text{MJ/m}^3$.

With the constitutive model calibrated to the rolling direction, the superelastic tensile response along other directions can be predicted. For brevity we show only the results of the finite-element predictions along the 50^o and 90^o (transverse direction) orientations to the rolling direction, in figures 3 and 4, respectively.

The superelastic response in these orientations is well-approximated by the predictions from the constitutive model. Of particular note, the anisotropic response between the rolling and transverse directions, as shown in figure 4, is captured by the model. To the best of our knowledge, this is the first time such calculations have been reported in the literature.

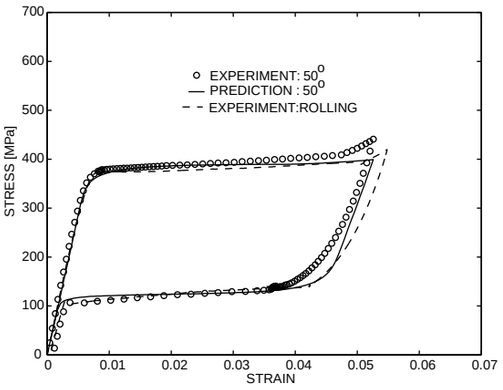

Fig. 3. Superelastic experiment along 50^o direction. The prediction from the full finite-element model for the polycrystal are also shown. For comparison purposes the tension experiment along the rolling direction is also shown.

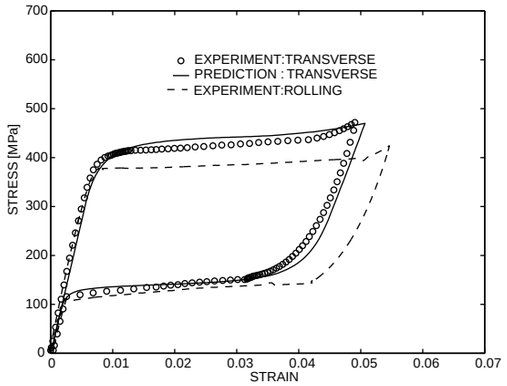

Fig. 4. Superelastic experiment along the transverse direction. The predictions from the full finite-element model for the polycrystal are also shown. For comparison purposes the tension experiment along the rolling direction is also shown.

IV. CONCLUSION

The crystal-mechanics-based constitutive model for phase transformations developed by Thamburaja and Anand [1] is shown to reasonably accurately predict the superelastic response of Ti-Ni sheet in tension along different in-plane directions. In particular, the rolling-transverse anisotropy of textured Ti-Ni sheet is captured by the constitutive model.

Acknowledgments

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