Accepted Manuscript

Influences of Granular Constraints and Surface Effects on the Heterogeneity of Elastic, Superelastic, and Plastic Responses of Polycrystalline Shape Memory Alloys

Harshad M. Paranjape, Partha P. Paul, Hemant Sharma, Peter Kenesei, Jun-Sang Park, T.W. Duerig, L. Catherine Brinson, Aaron P. Stebner

PII: S0022-5096(16)30881-X
DOI: 10.1016/j.jmps.2017.02.007
Reference: MPS 3064

To appear in: *Journal of the Mechanics and Physics of Solids*

Received date: 6 December 2016
Revised date: 5 February 2017
Accepted date: 5 February 2017

Please cite this article as: Harshad M. Paranjape, Partha P. Paul, Hemant Sharma, Peter Kenesei, Jun-Sang Park, T.W. Duerig, L. Catherine Brinson, Aaron P. Stebner, Influences of Granular Constraints and Surface Effects on the Heterogeneity of Elastic, Superelastic, and Plastic Responses of Polycrystalline Shape Memory Alloys, *Journal of the Mechanics and Physics of Solids* (2017), doi: 10.1016/j.jmps.2017.02.007

Influences of Granular Constraints and Surface Effects on the Heterogeneity of Elastic, Superelastic, and Plastic Responses of Polycrystalline Shape Memory Alloys

Harshad M. Paranjape[a,b,*], Partha P. Paul[b], Hemant Sharma[c], Peter Kenesei[c], Jun-Sang Park[c], T. W. Duerig[d], L. Catherine Brinson[b], Aaron P. Stebner[a]

[a] *Mechanical Engineering, Colorado School of Mines, Golden, CO 80401, USA*
[b] *Mechanical Engineering, Northwestern University, Evanston, IL 60208, USA*
[c] *Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439, USA*
[d] *Confluent Medical Technologies, Fremont, CA 94539, USA*

Abstract

Deformation heterogeneities at the microstructural length-scale developed in polycrystalline shape memory alloys (SMAs) during superelastic loading are studied using both experiments and simulations. *In situ* X-ray diffraction, specifically the far-field high energy diffraction microscopy (ff-HEDM) technique, was used to non-destructively measure the grain-averaged statistics of position, crystal orientation, elastic strain tensor, and volume for hundreds of austenite grains in a superelastically loaded nickel-titanium (NiTi) SMA. These experimental data were also used to create a synthetic microstructure within a finite element model. The development of intragranular stresses were then simulated during tensile loading of the model using anisotropic elasticity. Driving forces for phase transformation and slip were calculated from these stresses. The grain-average responses of individual austenite crystals examined before and after multiple stress-induced transformation events showed that grains in the specimen interior carry more axial stress than the surface grains as the superelastic response "shakes down". Examination of the heterogeneity within individual grains showed that regions near grain boundaries exhibit larger stress variation compared to the grain interiors. This intragranular heterogeneity is more strongly driven by the constraints of neighboring grains than the initial stress state and orientation of the individual grains.

Keywords: phase transformation (A), microstructures (A), polycrystalline material (B), finite elements (C), X-ray diffraction

1. Introduction

Shape memory alloys (SMAs) are a class of materials that may exhibit superelasticity, or the ability to fully recover large inelastic deformations induced by mechanical loading. The large inelastic strain during these events arises from a diffusionless solid-solid phase transformation between phases with high and low crystallographic symmetry. Equiatomic, polycrystalline nickel-titanium (NiTi) SMAs in particular can recover strains of up to 6% in transforming between a cubic austenite (B2) and a monoclinic martensite (B19$'$) phase. Because of this remarkable behavior, they are used for a variety of commercial applications (Duerig et al., 1999; Mohd Jani et al., 2014; Otsuka and Wayman, 1999). Due to the unique properties exhibited by SMAs and the resultant

*Corresponding Author
Email address: hparanja@mines.edu (Harshad M. Paranjape)