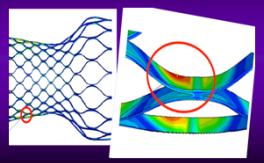
Advancement of Shape Memory Alloys for Heart Valve Stents through Predictive Science



PS&ED 2011-2012 Doctoral Cluster Program

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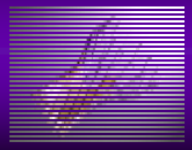


Background/Motivation

- Nitinol (NiTi) is a Shape Memory alloy used in biomedical applications such as **heart valve frames**
- Non-metallic carbide and oxide **inclusions** limit fatigue life
- Must design device for **zero probability of failure** (P=0) under service conditions

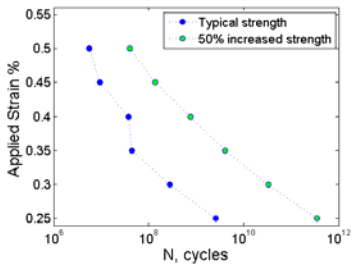
Design Objectives

- Address biocompatibility by identifying compositional constraints to minimize toxicity and hypersensitivity responses
- Quantify effect of NiTi **B2 matrix strength** on fatigue life
- Identify B2 matrix strength necessary for **P = 0 at 10^9 cycles**

Methods

- A fine-scale **3D reconstruction** of a single inclusion was made utilizing images from FIB/SEM serial sectioning
- FEA model utilizes crystal plasticity to predict **Fatigue Indication Parameter (FIP)** at different strain levels
- FIP calibrated to minimum Nf via Weibull analysis of experimental fatigue data

Fatigue Life Prediction

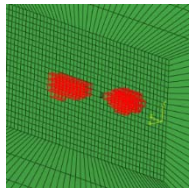


Predictive Science

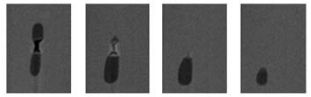
Engineering Design

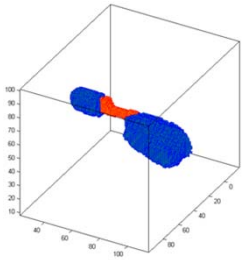
NORTHWESTERN UNIVERSITY

Finite Element Fatigue Simulation

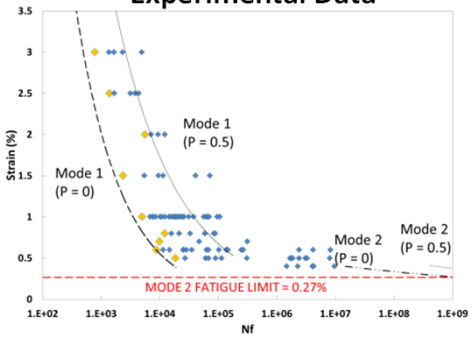


Microstructure Reconstruction

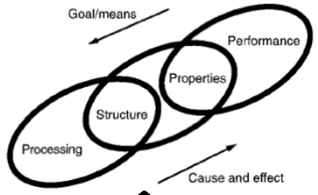




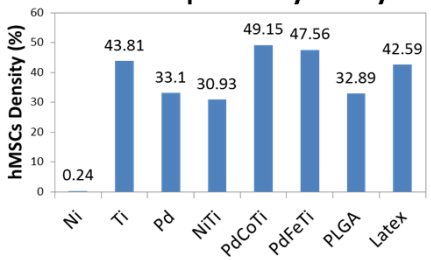
Model Calibration with Experimental Data



Alloy Design



Biocompatibility Study



Conclusions

- A 50% increase in B2 matrix strength from base NiTi strength levels resulted in an **increase in predicted fatigue threshold from 0.27% to 0.40%** strain amplitude at 10^9 cycles
- Fatigue life increases dramatically as inclusion size decreases
- Cell cytology study indicates **Pd is still a possible replacement for Ni** despite cross-sensitization reports in literature