DESIGN OF POROUS SHAPE MEMORY ALLOYS, PSED Cluster 2012-2013

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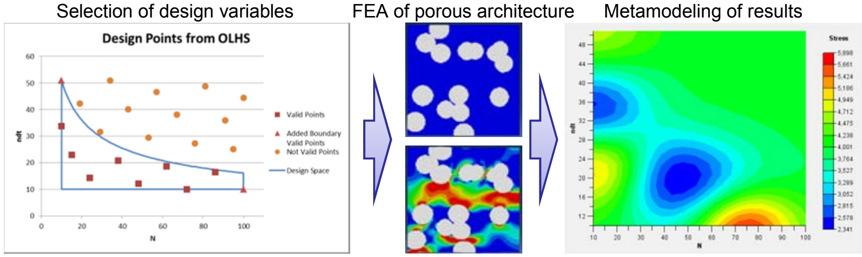
RESEARCH OBJECTIVE

The major objective of this interdisciplinary PSED cluster project is to develop the models that produce an optimized porous shape memory alloy (SMA) structure for use in medical bone implants. We plan to accomplish this by generating design inputs for the bone implants, designing a code that simulates porous SMA architecture, incorporating plasticity into an existing constitutive law, and performing FEA on the resulting porous architectures which will span both Engineering Design and Predictive Science.

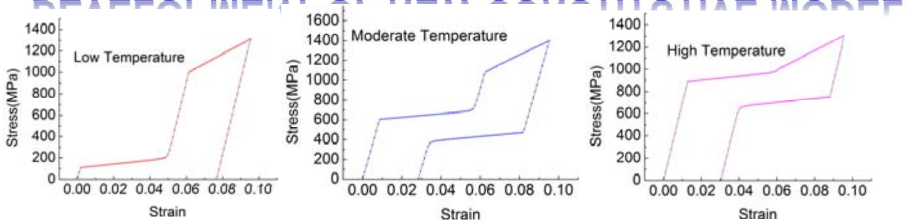
PREDICTIVE SCIENCE

Optimization of nearest distance between pores (ndt) and number of pores (N):

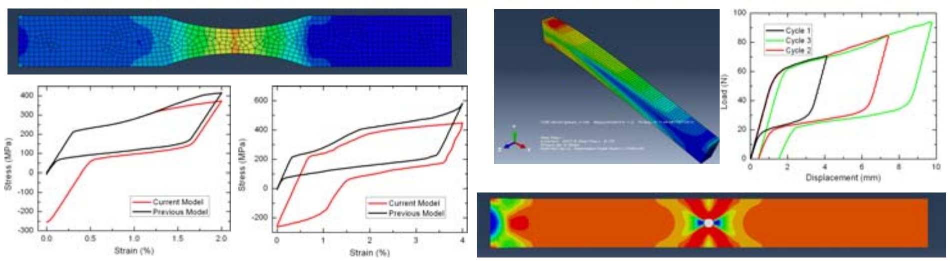
Selection of design variables — FEA of porous architecture — Metamodeling of results



DEVELOPMENT OF NEW CONSTITUTIVE MODEL

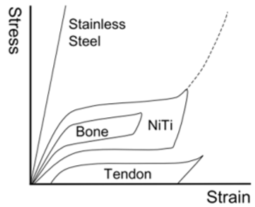


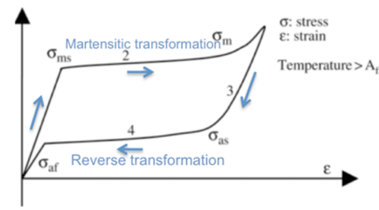
FEA OF STRUCTURES UNDER CYCLIC LOADING

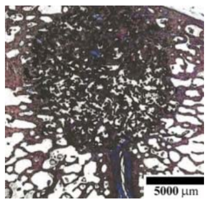


BACKGROUND

Porous SMAs have unique functional properties, such as superelasticity, a tailorable elastic response, limited weight, and ability for bone tissue ingrowth, specifically highlight porous SMAs as suitable candidates for the biomedical field for use as bone implants. Unlike other implant materials, SMAs are "superelastic" above their A_f temperature, which gives a stress-strain hysteresis due to transformation between austenite and martensite as seen below.







ENGINEERING DESIGN

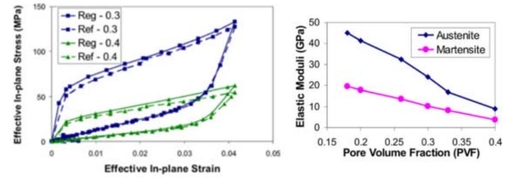
Design for Bone Ingrowth into Bone Implant:

Mean Pore Size (MPS):

- min 100 µm for bone ingrowth
- min 150 µm for osteon formation

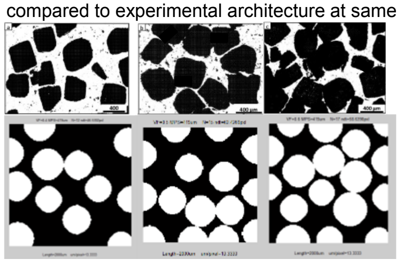
Pore Volume Fraction (PVF):

- 0.30 to 0.60, changed to vary elastic response:



Generated Porous Architecture:

Using MATLAB, porous architectures were created to simulate actual porous architectures. Simulated porous architecture are compared to experimental architecture at same MPS and PVF showing simulated architectures adequately capture the thin wall stress concentrations in the struts between pores and pore interconnectivity.



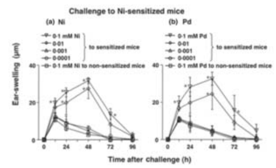
Biocompatibility:

Nickel allergy in 17% of women and 3% of men

Solutions:

Compositional change

- Exchange Ni for Pd
- Pd cross-sensitizes with Ni



Surface Treatment

- sufficient to keep Ni below stand dietary intake

Surface treatment	Ni release levels
Oxygen plasma (PIII)	0.06–0.18 ppm (untreated) 0.01–0.05 ppm (treated) 7–28 days
Oxygen plasma (PIII)	0.2–0.3 ppm (untreated) 0.05–0.08 ppm (treated) 70 days
Oxidation at 450 °C	0.45 ppm (untreated) 0.2 ppm (treated) 6 days
TiN and TiO_2-PVD coating; SBF soaking	0.66–0.85 ppm (not homogenized) 0.17–0.30 ppm (untreated) 0.04–0.09 ppm (TiN) 0.06–0.07 ppm (TiO_2) 0.05–0.07 ppm (SBF pre-soak) 0.03–0.04 ppm (TiN + SBF pre-soak) 0.06–0.07 ppm (TiO_2 + SBF pre-soak) 1–16 days
HNO_3/NaOH with HA coating	6.7 ppm (untreated) 0.48 ppm (treated) 50 days

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