Executive Summary

Two alloys (commercially pure titanium and the Ti-5-%Ni) were studied by a post-doc and a Master’s student (partial funding). Two new processes (one for each alloy) were developed to create porous structures, and the structure and properties of these materials were studied and found to be attractive for light-weight structural and actuation applications for energy-efficient aerospace transportation (airplanes).

Three journal papers have or will be submitted for publication. The MS student defended his thesis and graduated. This research will be the basis for submission of external proposals in the next 6-12 months.

A. Novel Process to Create Ti foams

This project was carried out by Dr. Bing Ye and led to one submitted publication (1).

Titanium foams with porosities of 30-70% have been produced by hot pressing of Ti/NaCl powder blends at 780 °C followed by dissolution of NaCl. The main findings are listed below:

1. NaCl is an attractive permanent space-holder for Ti powder densification for various reasons: (i) the high melting point of NaCl (as compared to previous fugitive space-holders used with Ti) allows full densification of Ti/NaCl blends at high pressures and temperature, ensuring the elimination of microporosity between Ti powders; (ii) NaCl is chemically unreactive with Ti, thus preventing contamination and degradation of mechanical properties; (iii) NaCl is highly soluble in water and can therefore be rapidly removed to create porosity; (iv) NaCl is non toxic and inexpensive.

2. For densification times less than 1h and relatively low stresses of 30-50 MPa, the titanium powders are nearly completely densified, insuring that the foam, after removal of the NaCl space-holder, has good mechanical properties. A foam with 50% porosity exhibits a Young’s modulus of 29 GPa, a compressive yield stress of 102 MPa, and ductile-like behavior for compressive strains >50%. Strength and stiffness decrease as porosity increases.
3. At the 780 °C hot pressing temperature, the NaCl powders deform much faster than the titanium powders. This results in faster densification of the Ti/NaCl blends as compared to pure Ti, and in flattening of the NaCl powders in the direction of the applied stress. The replicated pores created in the foam by NaCl removal therefore show elongated shapes that may be useful if foams with anisotropic structure and properties are desired.

B. Novel Process to Create Ti-Ni foams

This project was carried out by Mr. Anselm Neurohr and led to two publications (one submitted, the other to be submitted in September 2010 (2-3)). Mr. Neurohr also defended his MS thesis on the subject on August 26, 2010.

Woven steel meshes are used as space-holders for the fabrication of nickel-titanium (NiTi) shape-memory alloys with interconnected micro-channels in a two-step process. First, NiTi powders are hot-pressed around stacks of space-holders to produce steel/NiTi composites. Second, removal of the steel is performed by electrochemical dissolution, resulting in stacked, two-dimensional networks of cylindrical micro-channels that replicated the original wire meshes. This method permits independent control over the volume fraction, size, morphology, and orientation of micro-channels created in NiTi.

Prior carburization of the meshes results in the formation of a thin TiC layer at the steel/NiTi interface during densification that lines the surfaces of the micro-channels after steel dissolution and prevents the diffusion of iron into the NiTi matrix but also causes titanium depletion in the adjacent NiTi matrix. Without carburization, interdiffusion occurs between the steel and the NiTi, causing iron enrichment of the matrix near the micro-channels. In both cases, the transformation temperatures are decreased in the affected regions which can thus become superelastic.

Depending on the loading direction, loading stiffness values of 21-35 GPa are measured for specimens with 24% porosity, and of 15-25 GPa for specimens with 34% porosity. The highest stiffness is achieved when the loading direction is aligned with the porous layers and the lowest when loaded perpendicular to the porous layers. The stiffness values were compared to several common foam and composite models that, despite their greatly simplifying geometric assumptions, predicted reasonably accurate values useful for a first approximation.

The thermo-mechanical response of these structures, when loaded repeatedly to 4% strain, quickly approaches a steady-state such that the shape of the stress-strain curve, the stiffness, and the strain recovery remain unaffected by the number of cycles. The first several cycles contain irrecoverable plastic deformation that eventually settles out, resulting in complete shape recovery thereafter. This effect occurs after three and five cycles respectively in the 24% and 34% porosity specimens.

The strain recovery is unaffected by the loading direction: by a combination of elasticity and superelasticity on unloading and shape-memory on heating, the vast
The majority (93-98%) of an applied strain up to 6% can be recovered for both low and high porosity samples.

The mechanical and shape-memory properties of these structures – combined with the versatility in the channel geometries that can be fabricated by the present method – make them attractive for various applications, including light-weight, rapid response actuators for airplanes with variable geometry fuselage/engine shrouds to achieve higher efficiency.

C. Publications


2. A.J. Neurohr, D.C. Dunand

3. A.J. Neurohr, D.C. Dunand