National Aeronautics and Space Administration

Low Density Invar

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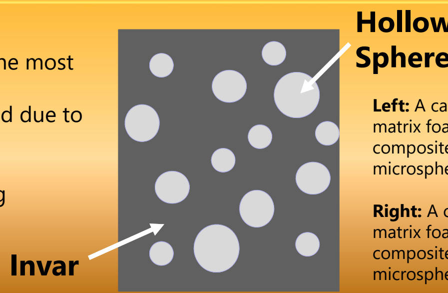
Program Category: SURP

Existing Problem

- Invar's high density limits its use to only the parts with the most stringent stability requirements.
- Traditional metal matrix foam techniques can not be used due to the high melting temperature.

Project Goal

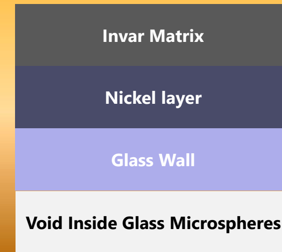
- Reduce the density of Invar by at least 20% by modifying traditional methods of metal matrix foam synthesis.
- Increase the specific strength.
- Maintain the thermal expansion properties of Invar.



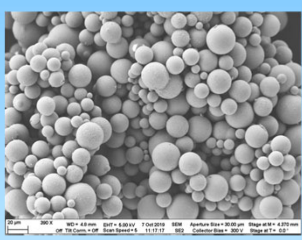
Left: A cartoon of the Invar matrix foam microstructure composite with Hollow glass microspheres.

Right: A cartoon of the Metal matrix foam microstructure composite with Hollow glass microspheres.

Glass-Invar Interface

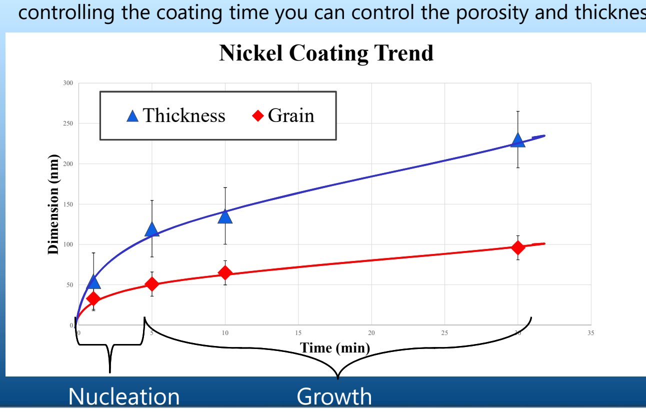


Hollow Glass Microspheres

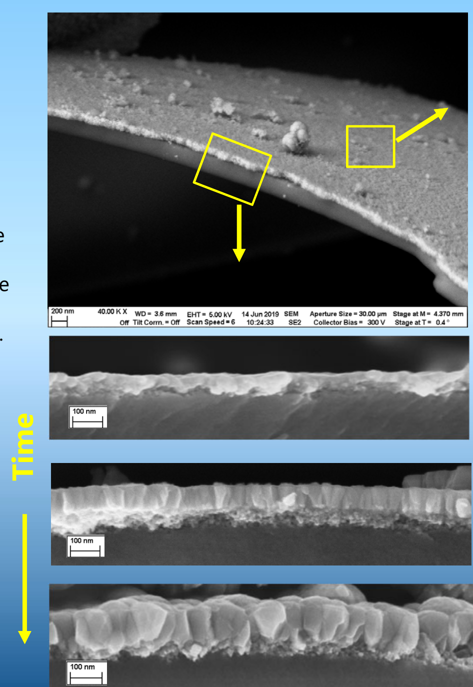


Left: An SEM image of 3M hollow glass microspheres
Bottom Left: A graph showing the nucleation and growth of the electroless nickel on the 3M glass.
Right: A FIB cross section of a single microsphere showing a uniform nickel coating.

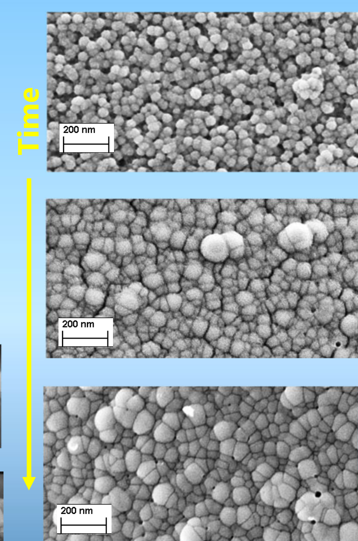
By using a nickel coating and the proper heat treatment, you can create hollow nickel microspheres with a glass shell. This allows higher temperatures and pressures for processing the metal foam, allowing the microspheres to be pressed and sintered without crushing. By controlling the coating time you can control the porosity and thickness.



Nickel-Glass Cross Section



Nickel Surface



Above & Left: Nanometer scale uniform electroless nickel coatings can have both their thickness an porosity controlled for different interfacial properties

Fabrication Conditions

Material	Electroless Nickel	Glass	Invar
Melting Temperature	~1200 °C	~1723 °C	1426 °C
Softening point	1000 °C	850-1000 °C	-----
Thermal conductivity	~12 W/m-°C	1 W/m-°C	10 W/m-°C

Iron alloy HIP treatments

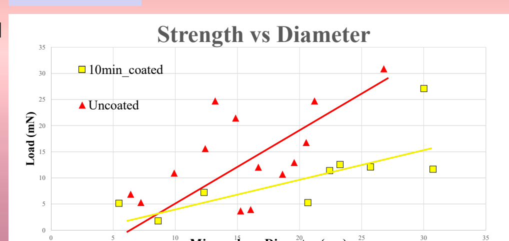
30-120 MPa

900-1200 C

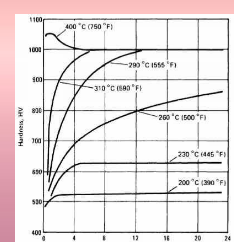
0.3 – 2 Hours

Spanning a design space of temperature, pressure, and time, different microstructure will be observed and an optimal one for bonding with the Invar powder will be determined. The optimum microstructure will have a minimum amount of deformed spheres, unwanted porosity, and dendritic interphases. Then different volume fractions of the microspheres will be tested and the mechanical and thermal expansion properties of the new metal matrix syntactic foams will be tested and examined. The microstructures will be examined with 3D X-ray nanotomography to ensure proper distribution of spheres and understand the amount of wall collapse. This work will have future applications in creating other metal matrix syntactic foams with high melting temperature metals. Additionally the nickel coated glass microspheres can be sintered together to create an extremely high energy absorbent material.

From analyzing the thermal properties of the materials used (above table), we still want to avoid melting the Invar. To do this, powder metallurgy will be used in the form of an induction hot press. We are custom fabricating the hot press and researching the literature for appropriate heat treatments. Common HIP heat treatments of iron based alloys have both wide ranges of times, pressures and temperatures. To protect the microspheres we will utilize the lower temperatures and pressures and longer times and then move the design space forward.



Left: A plot showing the strength trends of the microspheres before and after the electroless coating. The electroless coating introduces surface flaws that increase the probability of failure in the glass which is represented by the lower strength of the coated spheres
Right: A plot showing the increase in hardness of electroless nickel and subsequentially the increase in strength. This shows that although the glass is weakened with the nickel coating process, the coating can be heat treated to be stronger than the initial glass microsphere.



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