U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

AMMTO & IEDO JOINT PEER REVIEW

May 16th-18th, 2023

Washington, D.C.

Advanced Bearing Materials for Harsh Service Conditions| AMMTO

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2553-1641 **|** Oct. 1, 2022 – Sept. 30, 2024

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Project Overview

- **This project supports the AMMTO mission of advancing energy-related materials and manufacturing technologies to increase domestic competitiveness and building a clean, decarbonized economy by:**
  1. Significantly reducing the cost of large-scale wind turbines, particularly offshore, by addressing known failure modes with current materials.
  2. Addressing a roadblock to commercially-viable cryogenic hydrogen pumps needed for distribution and fueling gas turbines for electricity and propulsion.
- **Challenges:**
  – Hydrogen embrittlement and corrosion-assisted fatigue damage in bearings.
- **Impacts:**
  – Estimated 20-40% reduction in the O&M costs of wind turbines.
  – Demonstration of an LH_2-tolerant bearing material to enable H-economy.

Project Outline

Innovation: Shape-memory and multi-principal-element bearing alloys.

Project Lead: Ames National Laboratory

Project Partners: Argonne National Laboratory, Raytheon Technologies Research Center, Timken Co., and Retech Systems LLC

Timeline: October 1, 2022 – September 30, 2024, 29% complete

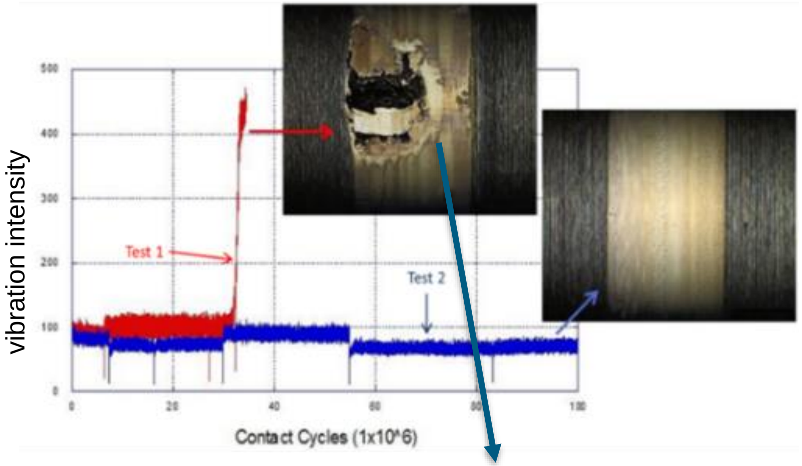
Budget:

	FY22 Costs	FY23 Costs	Total Planned Funding
DOE Funded	$1M	$1M	$2M
Project Cost Share	$250k	$250k	$500k

End Project Goal: Demonstrate prototype bearings of new lightweight high-entropy and shape memory alloys that exhibit an improvement in bearing lifetime of >100% for wind turbine and >1000% for LH2 gas turbine pump applications.

Background & Strategic Approach

Challenge 1: Premature failure of wind turbine bearings due to corrosion-enhanced high-cycle fatigue.

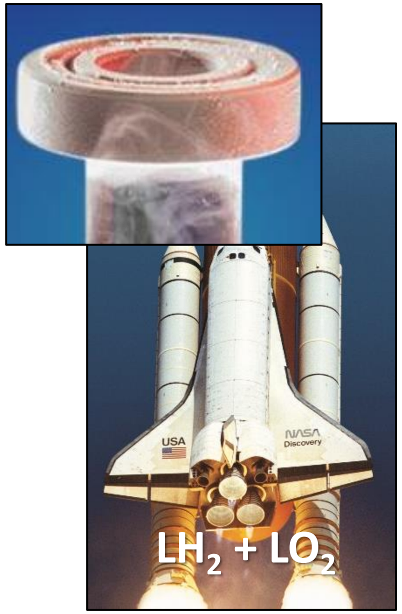


fatigue-cracks

Premature bearing failures, typically at 80-95% ***below*** rated service life, constitute ***more than 50%*** of wind turbine generator failures[1]. This is a key challenge to reducing the cost of off-shore wind turbines.

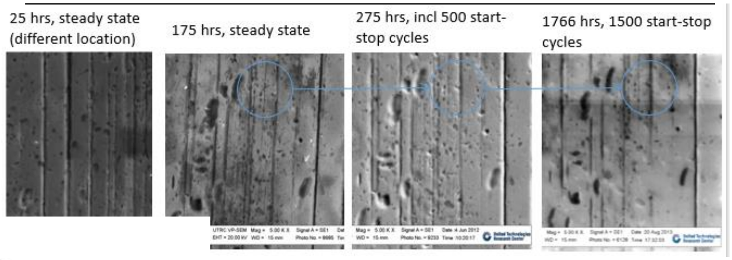
[1]NREL Gearbox Reliability Database

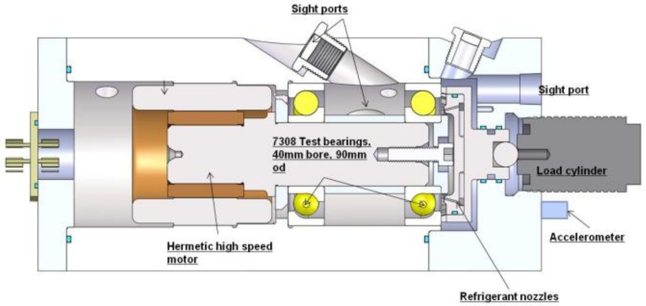
Challenge 2: Long-duration hydrogen-compatible bearing materials are commercially non-existent.



LH_2 handling and fueling of gas turbines requires pumps, and SOTA bearing materials last ~10h. Viability depends on achieving ~ 1000h (annual) maintenance schedules.

Wear progression in bearing lubricated with pure (LN_2) refrigerant over 1,766 hours





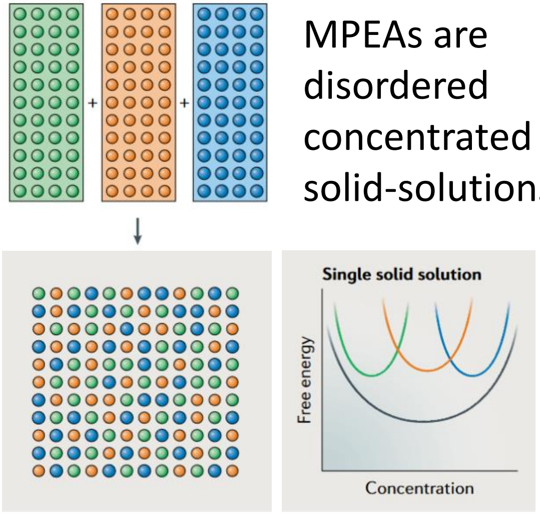
Hermetic bearing tester used for pure refrigerant lubrication

Raytheon Technologies

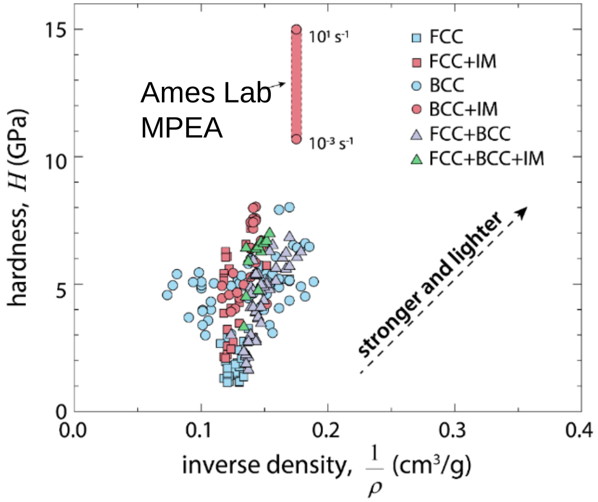
Commonality: corrosion-enhanced embrittlement damage.

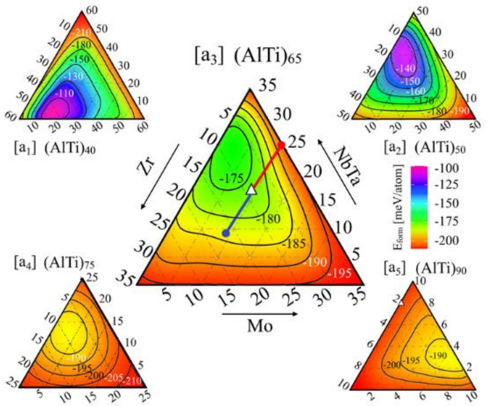
Background & Strategic Approach

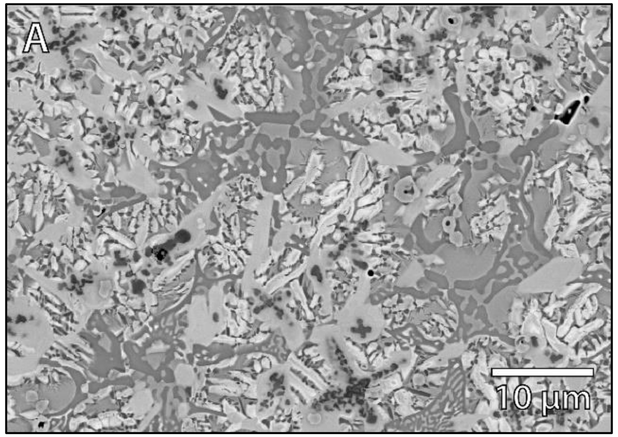
Lightweight, High-Hardness, Multi-phase **Multi-Principal-Element Alloy (MPEA)**



MPEAs are disordered concentrated solid-solutions







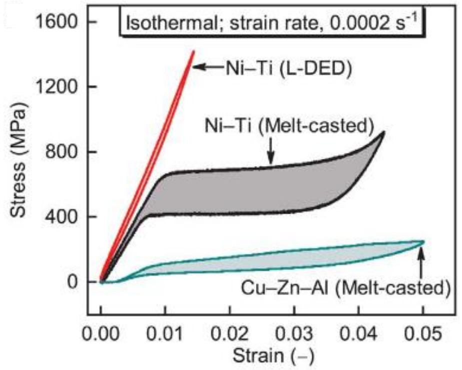
Ames-led work published in App. Mat. Today (2023)

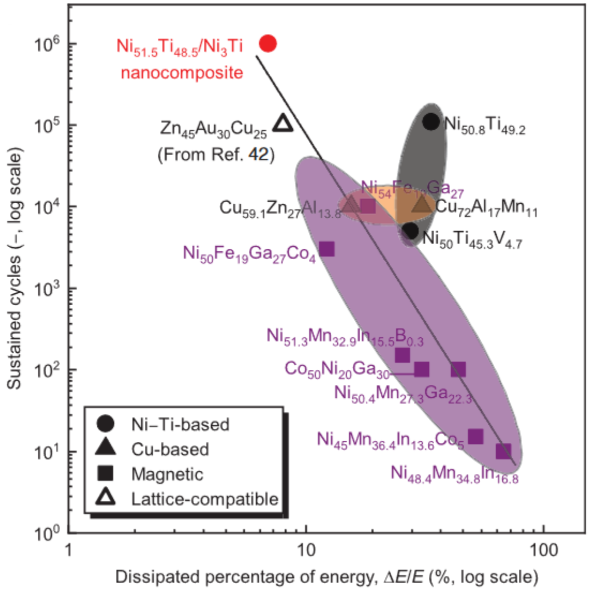
Powder-based, corrosion and fatigue-resistant **shape-memory alloys (SMAs) enabled by Ce-doping**

Recent work by Ames and collaborators showed that powder-based rapid solidification enables extremely superelastic behavior in SMAs like Ni-Ti.

This project will demonstrate how Ce-doping and rapid solidification of powders can enable bulk parts.

This addresses a hurdle that impeded earlier work on SMA bearings deployment by NASA.

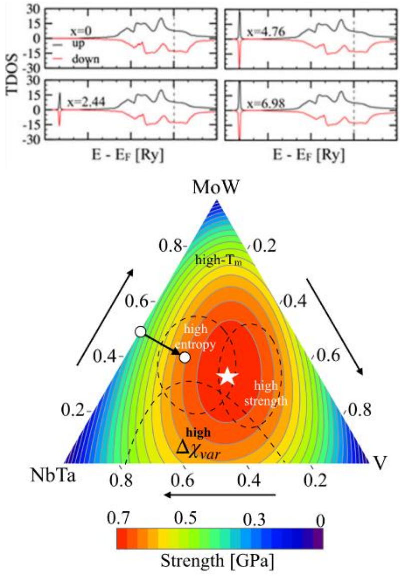




Collaborative work published in Science (2019)

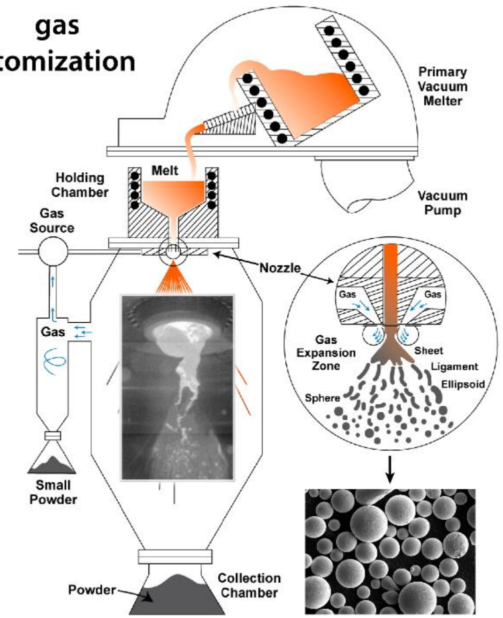
Background & Strategic Approach

theory-guided composition tuning in Q1-Q2



Alloy Powder Production

gas atomization



lab-scale (1-2 kg)

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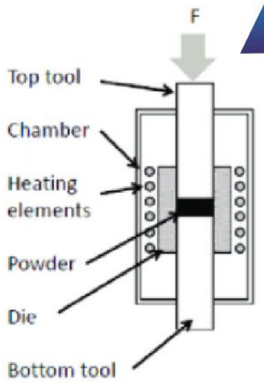
pilot-scale (10+ kg)

RETECH

Manufacturing & Materials Characterization

hot isostatic pressing (HIP)



mechanical testing

precision machining

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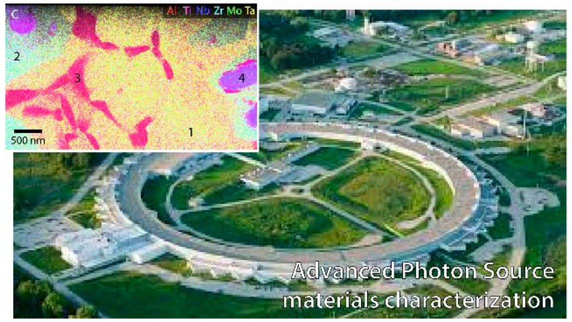


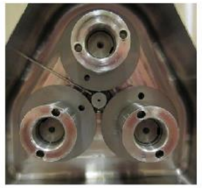
Prototype Bearing Testing

Raytheon Technologies

liquid hydrogen lubricated testing

TIMKEN

endurance testing (wind)



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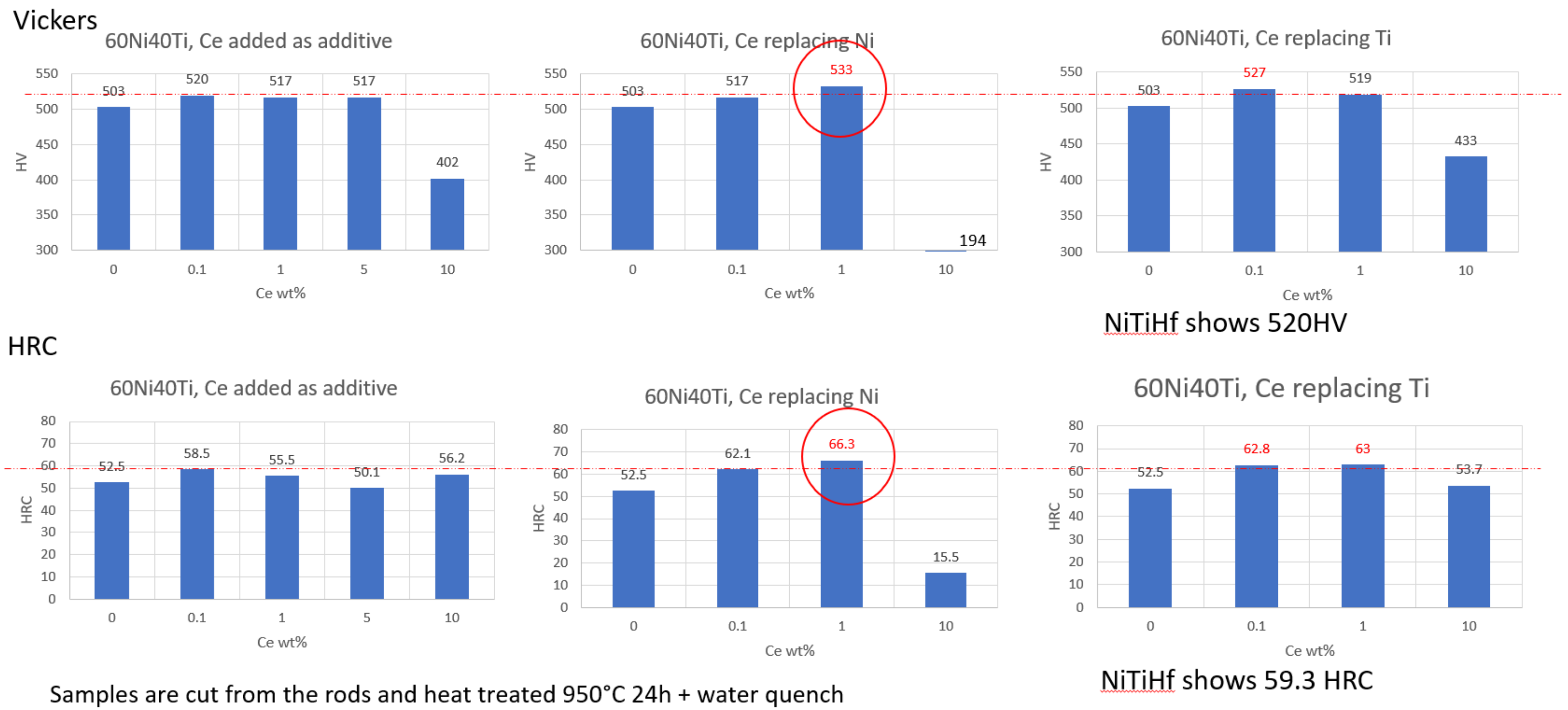
accelerated failure testing

Results and Achievements

Castings of Ce-doped Ni-Ti



Samples are cut from the rods and heat treated 950°C 24h + water quench

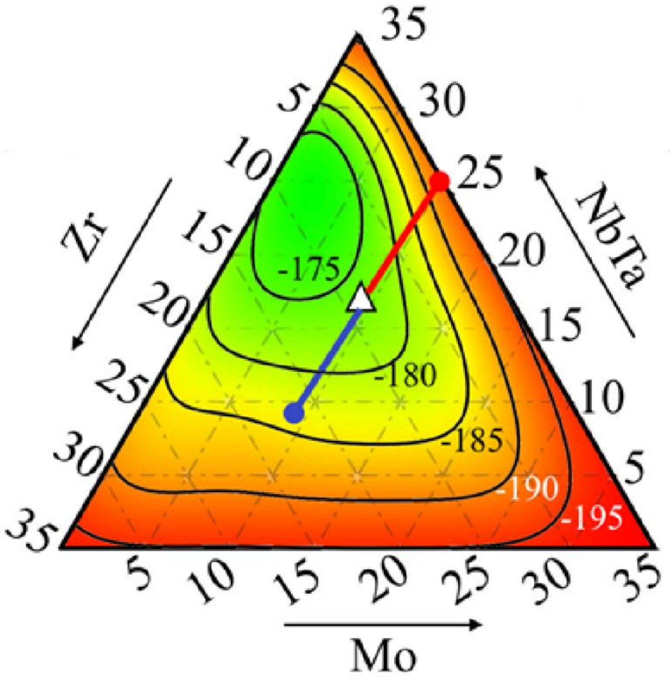
- Rapid casting and determination of hardness used as selection criterion, compared to SOTA Hf-doped Ni-Ti work from NASA; 13 compositions were cast into rods and tested (above).
- Samples showed good castability for 0.1, 1.0, and 5.0 wt.% Ce, but embrittlement at 10 wt.%.
- Ni-Ti baseline alloy shows sub-room-temperature phase transformation, as expected.
- 1 wt.% Ce (replacing Ni, better than equally replacing Ni+Ti) selected: **$Ni_{59}Ti_{40}Ce_{1}$ wt.%**

Results and Achievements

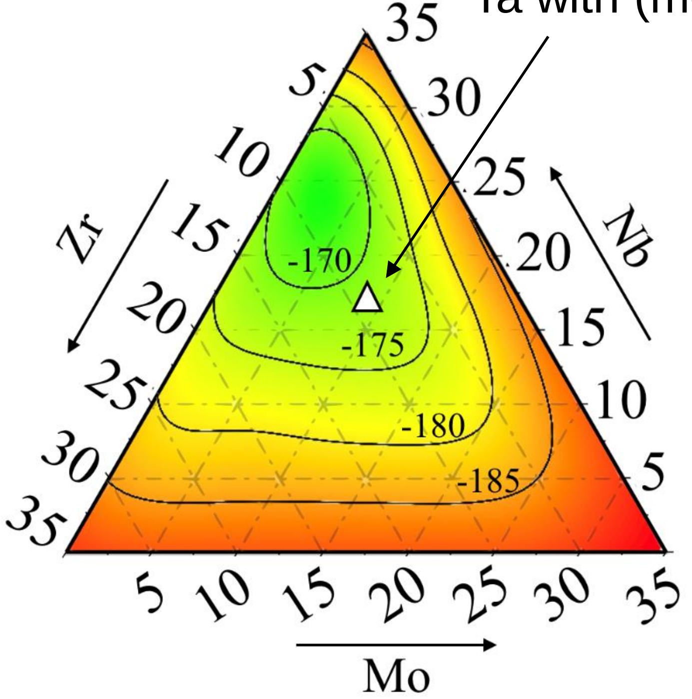
DFT/theory-guided optimization of HEA completed. Below are pseudo-ternary diagrams show **formation enthalpies in** units of meV/atom (~0.1 kJ/mol)

Formation-energy landscape indicates negligible change in alloy behavior by completely replacing Ta with (more) Nb.

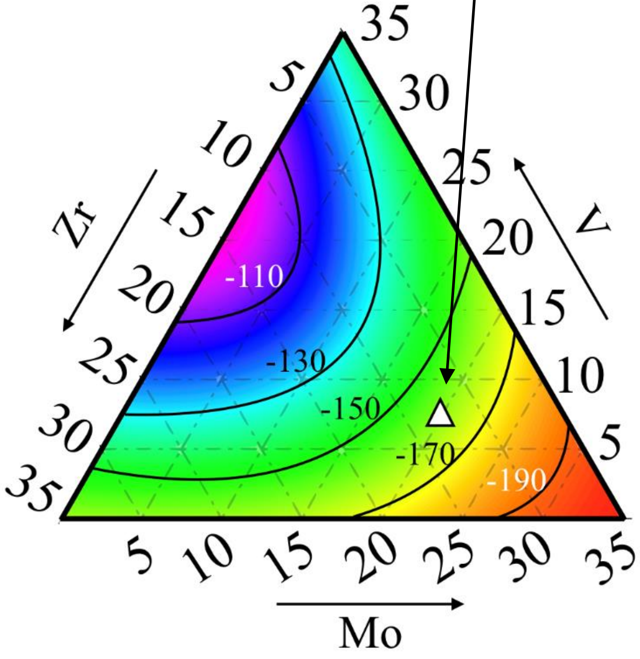
Vanadium was calculated to be another viable alternative to Ta+Nb



$(Al_{33}Ti_{33})$



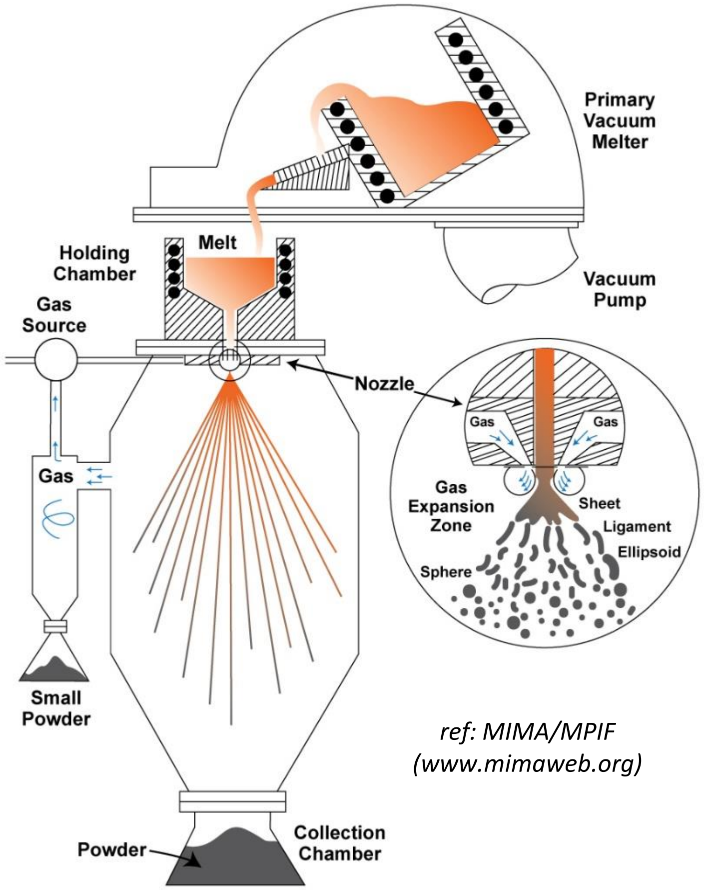
$(Al_{33}Ti_{33})$



$(Al_{33}Ti_{33})$

Results and Achievements

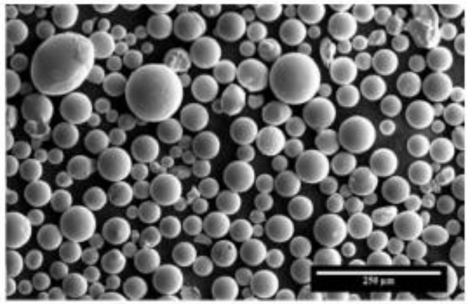
Gas Atomization



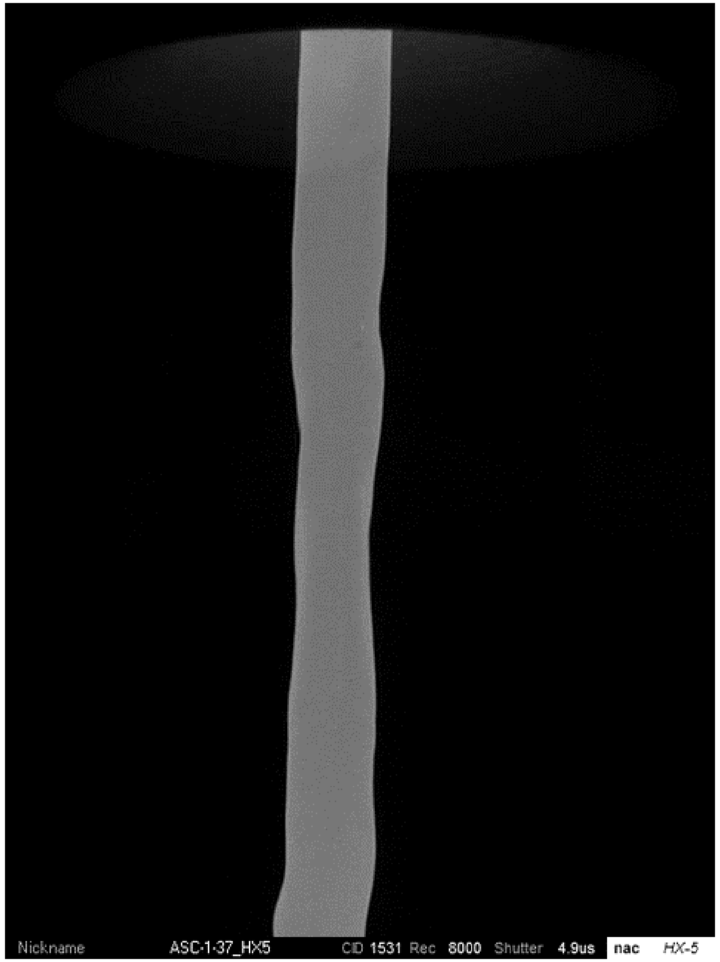
ref: MIMA/MPIF (www.mimaweb.org)

view of melt pour

SEM of high-purity, uniform powder output



view of gas-die injection



In-progress this quarter: gas atomization to produce Ce-doped Ni-Ti and MPEA powders for consolidation into test coupons and testing at Ames and Argonne, followed by small (~10-20 mm) bearing manufacturing & testing.

Future Work, Technology Transfer, & Impact

Future Work:

- Pilot-scale gas atomization to produce Ce-doped Ni-Ti (shape-memory) and Al-Ti-Nb-Zr-Mo-Ta (multi-principal-element) alloy powders
- Hot-isostatic pressing (HIP) consolidation and mechanical testing at coupon scale by Ames, and pilot-scale endurance testing by Timken and accelerated failure testing by ANL.
- Construction of LH_2 immersion bearing test apparatus led by RTRC for baseline and experimental alloy testing.

Technology Transfer:

- The team includes key stakeholders that will help promote and accelerate successful deployment of the new bearing alloys for wind, including bearing a component-level OEM (Timken Co.).
- System-level manufacturing of cryogenic-hydrogen pumps, needed for next-generation H-fueled gas turbines, will be pursued by RTRC, pending a successful demonstration at the coupon-level.

Impact:

- New bearing alloys with superior corrosion and damage tolerance are expected to double large-scale wind-turbine bearing lifetimes and reduce maintenance costs.
- Demonstration of a viable LH2 pump bearing alloy that can survive prolonged use, with annual maintenance cycles, would be a disruptive technological achievement in a market with no demonstrated viable commercial competitor.

Questions?

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