A New Method of Low Cost Production of Ti Alloys to Reduce Energy Consumption of Mechanical Systems

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University of Utah, Ametek, Ford, ARL
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Z. Zak Fang, PI, Univ. of Utah
Ravi Chandran, Co-PI, Univ. of Utah

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Project Objective

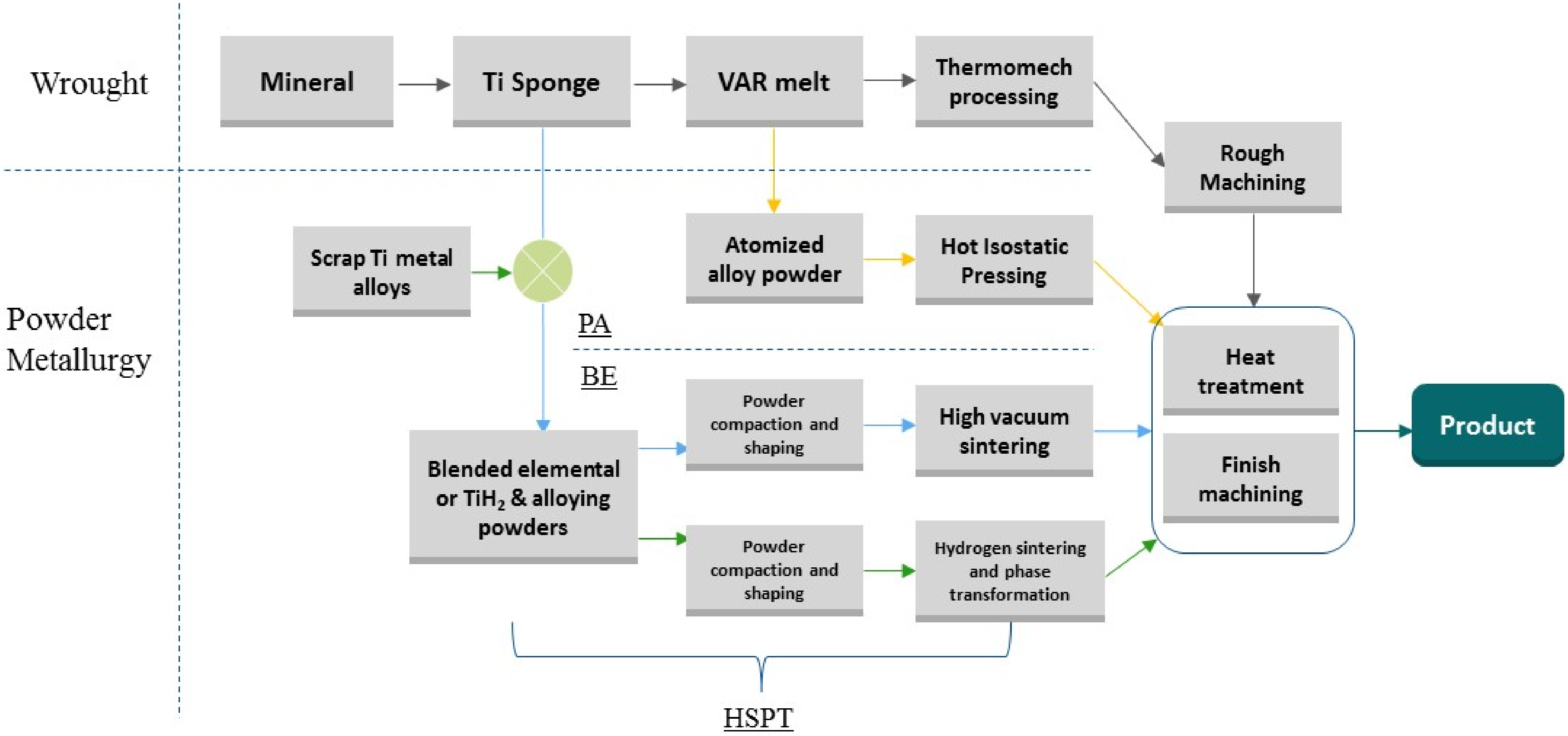
- Develop a novel low cost method for manufacturing Ti
- Demonstrate the mechanical properties of Ti using the new method to be equivalent to that of wrought Ti at a fraction of its cost.
- Initiate efforts to promote the use of Ti in automobiles, balancing the energy and cost considerations

- Traditional wrought Ti is too expensive
- Traditional powder metallurgy Ti is either inferior, or lacks significant cost advantage

- Affinity of Ti to oxygen makes Ti extraction, melt refining, forging / rolling, and machining, all extraordinarily costly

Technical Innovation and Approach

Manufacturing Routes of Ti Products



Technical Innovation and Approach

Powder metallurgy is considered a low cost alternative, but…

Issues plaguing conventional PM Ti after 4 decades

Mechanical properties

- Fracture toughness
- Fatigue performance

Microstructure

- **Coarse lamellar as-sintered microstructure**
- Oxygen and other impurity levels
- Residual porosity

Cost

- Cost of high pressure consolidation / sintering
- Post-sintering thermal mechanical processing cost
- **High performance/cost ratio – P/C?**

Technical Innovation and Approach

To address these issues:

- **Obtain wrought-like microstructure including**
  - grain microstructure,
  - oxygen – near or <0.2%,
  - eliminate porosity when necessary

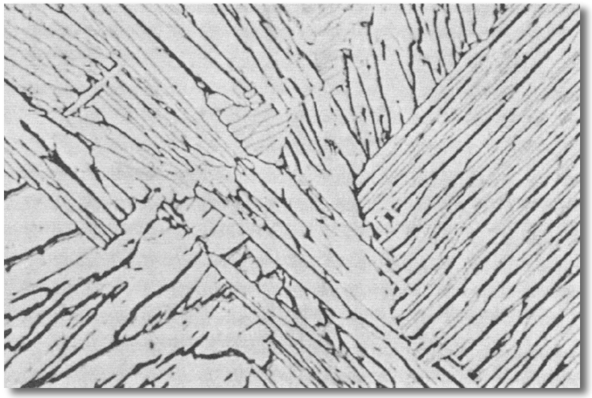
- **Do so without resorting to wrought processing or other high pressure sintering processes**

HOW?

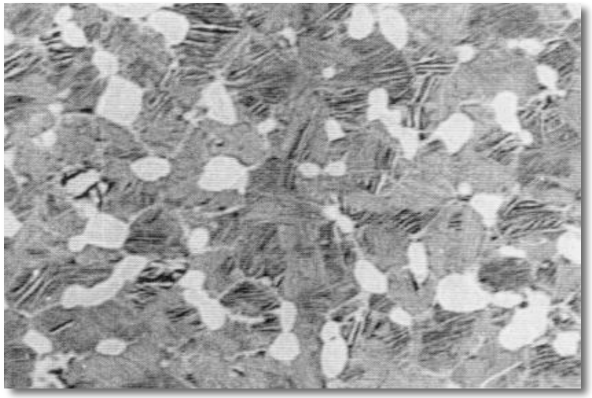
Technical Innovation and Approach

Typical Wrought Ti-6Al-4V Heat Treated Microstructures

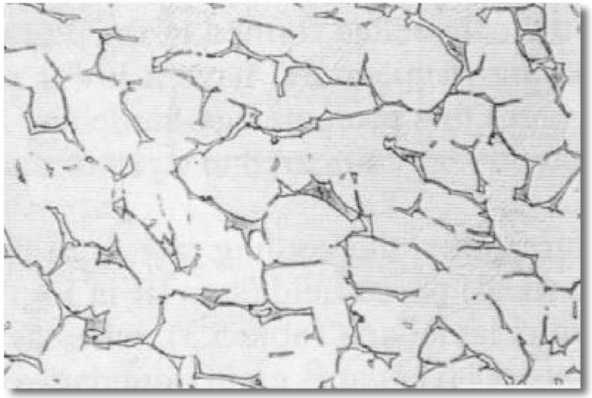
There are three general types of microstructure in α+β alloys:



Fully lamellar:
Typical Widmanstatten structure. Transformed β consisting of α plates with β between them.



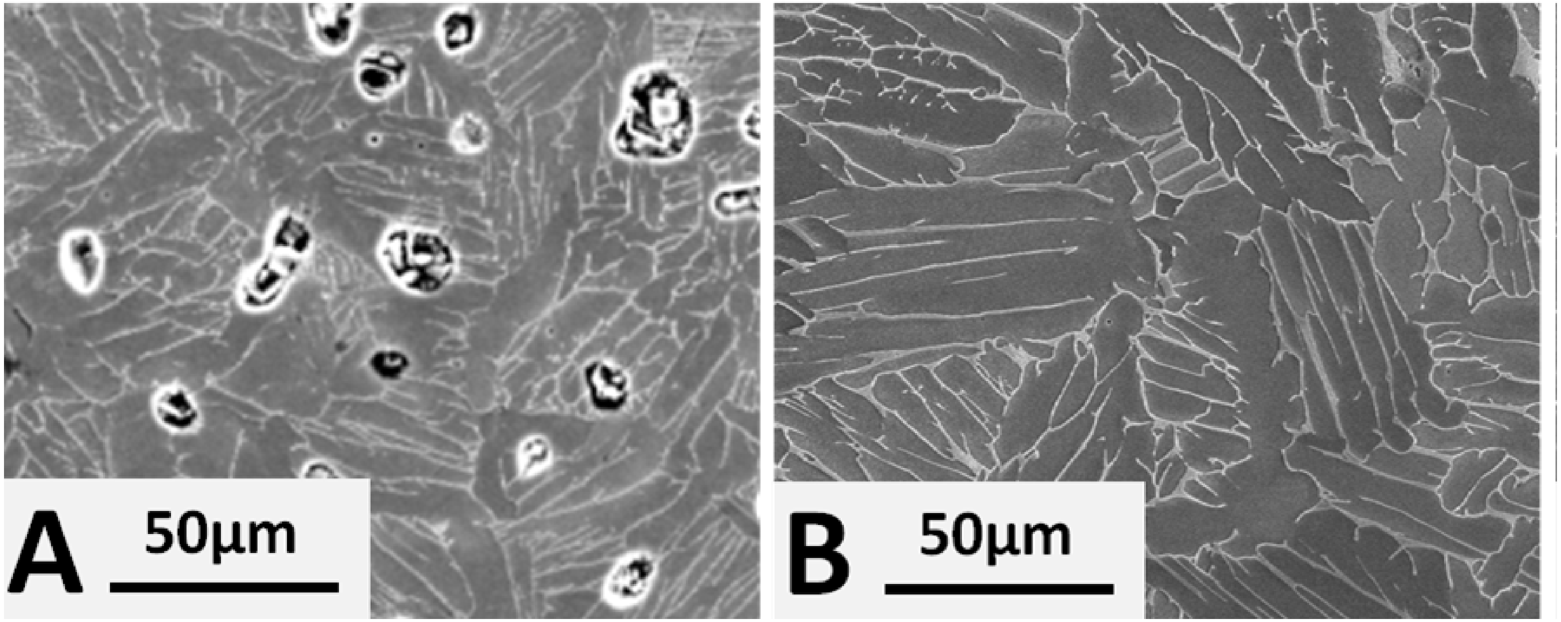
Bi-modal (duplex):
Equiaxed primary α (αP) in a lamellar α+β (transformed β) matrix.



Globular
Equiaxed primary α (αP) grains with the equilibrium fraction of β formed only at the triple points of α grains.

Technical Innovation and Approach

Microstructure of vacuum sintered Ti-6Al-4V

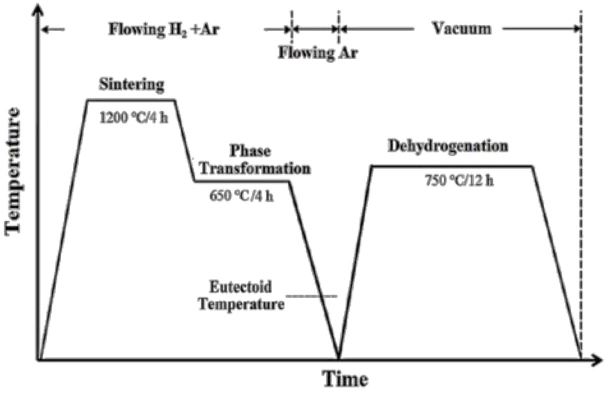


Vacuum Sintered Ti
- *Poor densification*
- *Coarse microstructure*

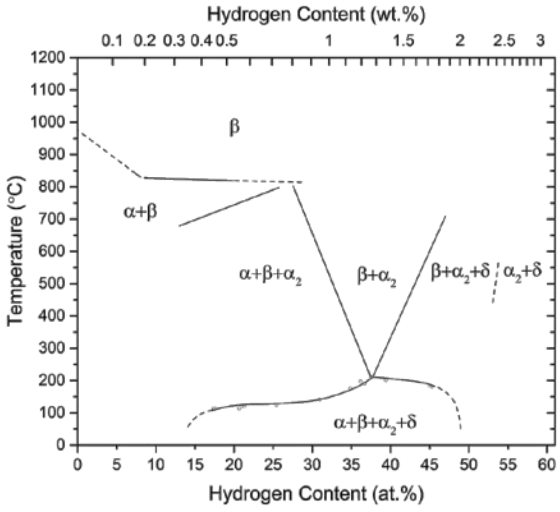
Vacuum Sintered TiH_2
- *Significantly improved densification*
- *Coarse microstructure*

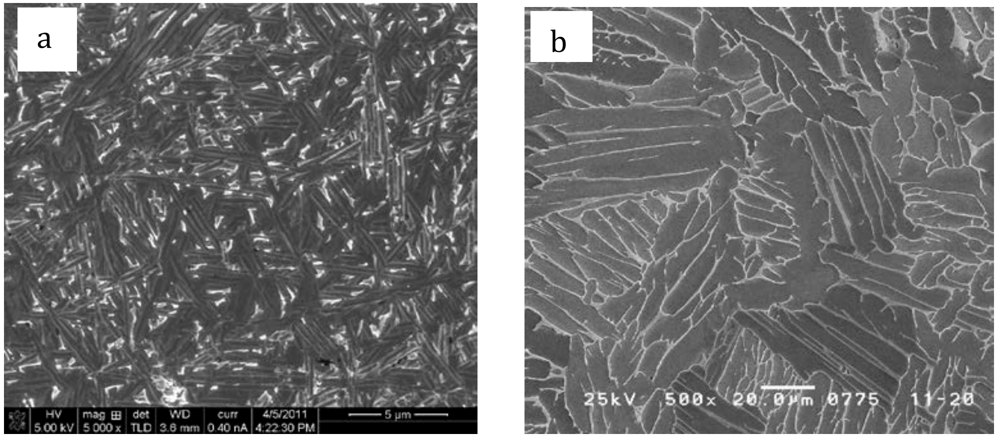
Technical Innovation and Approach

***Novel innovation*: Hydrogen Sintering and phase transformation (HSPT)**



- Refine grain sizes by controlling H_2 content and phase transformation in as-sintered state
- High density - >99%
- Small pore size - <1 mic.
- Maximize Performance / cost ratio





Microstructures produced by sintering of TiH_2 in (a) hydrogen, (b) vacuum (SEM)

Technical Innovation and Approach

Microstructure comparison: HSPT vs. vacuum-sintered vs. heat-treated vs. wrought Ti-6Al-4V

Wrought Ti-6Al-4V*

a) fully equaixed microstructure

b) bi-modal microstructure

HSPT Ti-6Al-4V**

c) as-sintered

d) after quenching heat-treatment

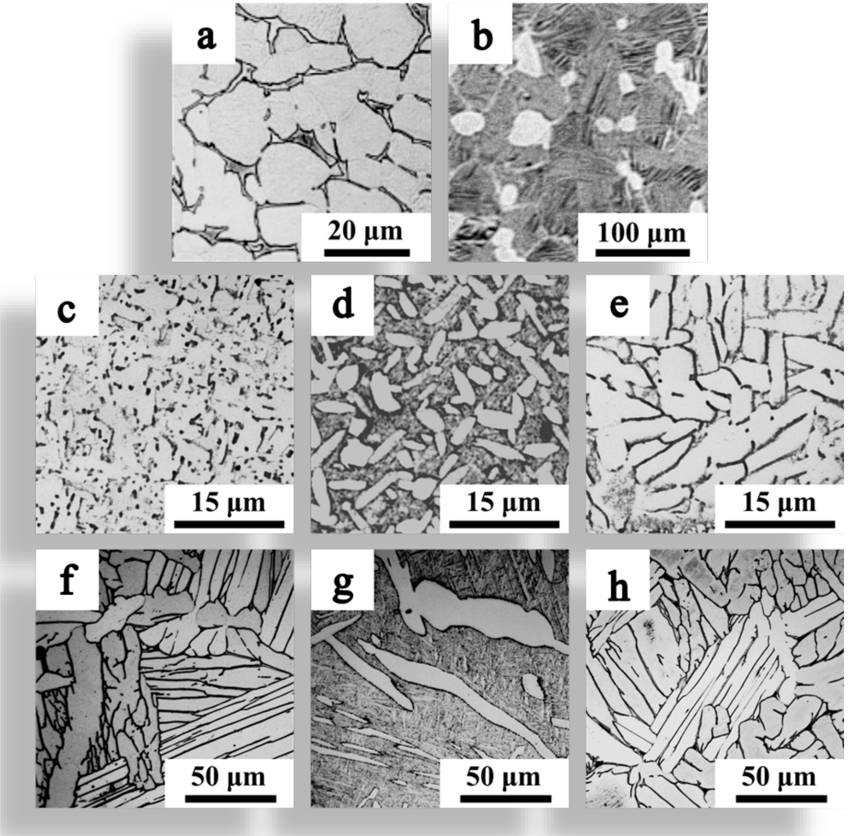
e) after furnace-cooling heat-treatment

Vacuum-sintered Ti-6Al-4V**

f) as-sintered

g) after quenching heat-treatment

h) after furnace-cooling heat-treatment



- HSPT Ti-6Al-4V is capable of forming wrought-like (globularized or bi-modal) microstructure via simple heat treatments without TMP, while vacuum-sintered Ti-6Al-4V does not have this capability.

Transition and Deployment

- Who cares?
  - – Light weight/high specific strength
  - - High temp. corrosion resistance
- Who is the end user?
  - - Aerospace, chemical processing, bio medical
  - - **Automobile:** reciprocal weight – fuel economy
    exhaust components – high T corrosion
    all other PM steel components
- Technology licensed to Ametek – a tier one supplier
  - Fully proven in the lab. If there will ever be Ti used in automobiles, this is the best technology.
- Market barriers and response:
  - Why people, including the user industry and even DOE, are not really embracing, promoting, or using it?
  - Need the right messenger?
  - Need marketing campaign to educate end users, part makers, funding agencies, and investors.
  - Identify key market entry points, grow market to reach economy of scale

Measure of Success

- Primary goal is to produce Ti with superior properties at 1/10th to 1/5th cost of current state-of-the-art.

  If we are successful -

- Automobiles can and will start using Ti to replace steel
  - ORNL case study estimates life cycle energy savings through use phase when substituting 18 kg HSPT or Kroll-wrought-machined Ti for 36 kg steel in vehicles:
    - 3,500 MJ savings per HSPT vehicle
    - Energy penalty of 157,000 MJ per Kroll-wrought-machined Ti vehicle
  - Benefits in "use phase" of Kroll/wrought Ti does not outweigh the energy consumption of manufacturing, but,
  - HSPT Ti breaks even in six years compared with using steel
  - At US LDV fleet level, savings of ~50 TBtu annually by 2050 with HSPT

Project Management & Budget

- Duration of the project – 3 years
- Project task and key milestone schedule

	Description	**Schedule**
Milestone I	A single source of powder selected for the project	Dec. 1, 2013
Milestone II	Ti-6Al-4V microstructure targets: >98% density, Grain size < 2 µm , Oxygen % < 0.3%	Aug. 30, 2013
Milestone III	Mechanical property targets: Tensile – 900 MPa, Elongation >10%, Fatigue limit: 500-600 MPa	Aug. 30, 2014

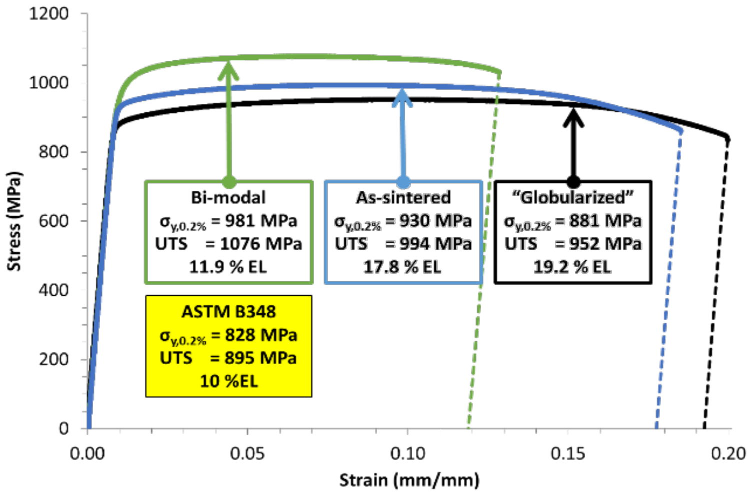
- Project budget

Total Project Budget	
DOE Investment	$1,460,285
Cost Share	$370,000
Project Total	$1,830,285

Results and Accomplishments

- The process technology has been repeatedly demonstrated, robust
- Wrought-like microstructure achieved
- Wrought-like mechanical properties including both static and fatigue strength targets achieved

Static tensile properties



Fatigue endurance limit