Low-Cost Titanium Powder for Feedstock

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Outline

- **Purpose**
- **Barriers**
- **Motivation – Large potential vehicle mass savings**
- **Approach**
  - Survey emerging titanium technologies
    - Cost Analysis
    - Evaluate the product quality
  - As-needed develop process parameters to consolidate the new materials
- **Progress**
  - Cost Study – ITP Powders
  - Low Cost $TiCl_4$
  - Powders from Low-Cost $TiCl_4$
    - Morphology
    - Mechanical Properties
    - Sintering behavior
  - Consolidation by Direct Press and Sinter – Lowest Cost Process
    - High Rate Gear Production Trials
- **Technology Transfer**
- **Conclusions – To Date**
- **Next Steps – FY 08**
  - Cost analysis of 2 new processes
  - Fabrication of high strength beta alloy in rod form
- **Publications**

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Purpose

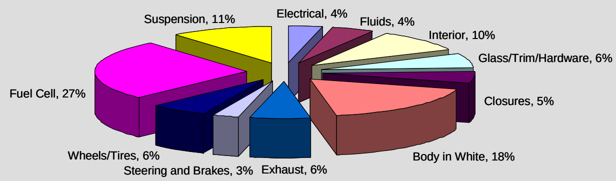
- The purpose is to develop and demonstrate technologies for producing automotive components out of titanium and titanium alloys at ever-lower costs.
  - Develop low cost titanium powder for use in Powder Metallurgy (P/M) components and EB Hearth Melting
    - Utilize powders from emerging low cost powder production technologies and low cost feed stocks
  - Develop, as-needed, parameters for powder and press and sinter technology for low cost Ti powders to facilitate commercialization

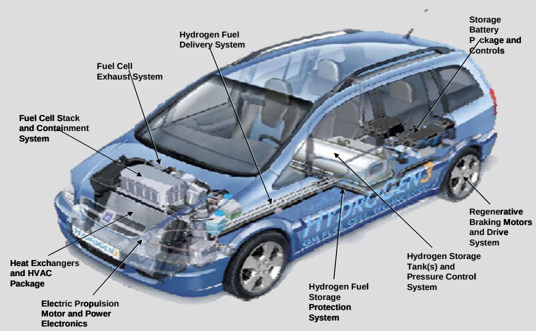
Barriers

- Titanium is the only lightweighting material that can be substituted for high strength and corrosion resistant steels used in automotive applications.
  - Titanium can be used in suspension, fuel cells, fasteners, reciprocating components etc… with individual component mass savings of up to 70% (hollow core springs) over incumbent materials.
  - Technically titanium has been demonstrated in many automotive applications in low-volume highly specialized vehicles.
- The barriers to realizing the mass savings associated with titanium in high-volume vehicles have been:
  - Raw material cost
  - Secondary processing cost

- Performance benefits are real
  - 14 auto OEMs have used titanium components in production vehicles.
    - Ranging from massive springs to small washers
- Reduced cost required for implementation into *high production* volume vehicle
  - Powder Metallurgy with powder cost less than $4/kg
    - Can't be met with current Kroll or Hunter processing

Overview of Fuel Cell Materials Needs





Total Vehicle Savings With Ti Intensive Materials Substitution
Neglecting Body-in-White

	Steel or Stainless Steel, kg	Titanium, kg	% Savings with Ti
Fuel Cell Power Unit	300	197	34%
Vehicle Structure	818	647	21%
Total Fuel Cell Vehicle	1118	844	**25%**

- A 10% mass savings in an automobile can result in fuel economy improvements from 1 to 3% - model dependent.
  - Titanium impact on US fuel usage is potentially very high
- A similar study by GM suggested that 60% of the mass of the chassis alone could be saved. (Kim et al. 2006)
  - *Technical feasibility demonstrated for many of the applications considered*

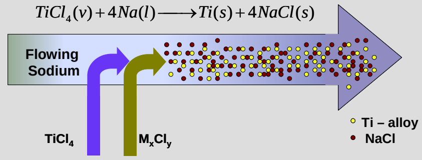
Approach

- The approach of this project will be to produce and evaluate low cost titanium powders using feedstock materials that allow for the production of commercially pure and alloyed powders approaching the FreedomCAR cost goals.
  - Funding low-cost powder production and processing demonstrations for emerging Ti powder technologies.
  - Perform cost analysis of emerging titanium powder technologies.
    - Perform enabling tasks – such as demonstration of low cost powders produced from $TiCl_4$ from ilmenite
  - Develop process parameters for low cost consolidation.
    - Press/sinter and powder forging
  - Evaluate the suitability of low cost powder for feedstock in EB Hearth Melting – *works very well not discussed.*

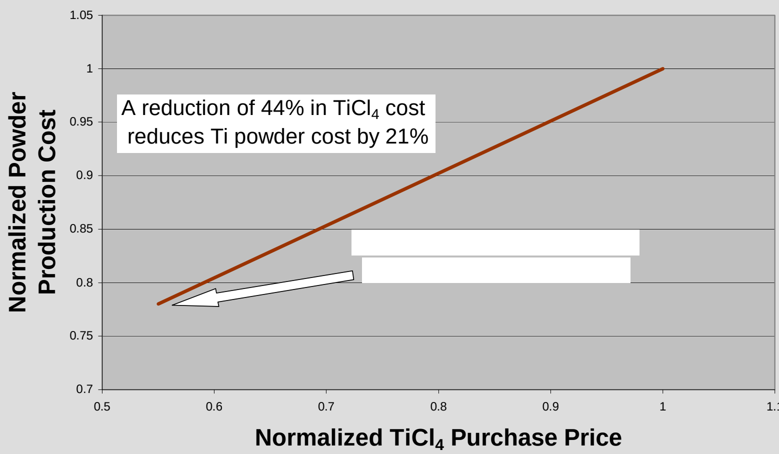
Results - Cost Analysis

- Can the new Ti technologies meet the automotive hurdle?
- Contracted Camanoe Associates to analyze selected processes
  - Technical cost model that evaluated several emerging powder technologies – up to solid-state consolidation of a slab
    - A sampling from more 20 new technologies (EH Kraft 2005)
  - Selected International Titanium Powder (ITP) process for further evaluation
    - Potential final powder cost, predicted to be less than the automotive industry hurdle in the “optimistic” scenario
      - Continuous low cost conversion process dependent upon raw materials
    - The ability to directly produce alloy powders

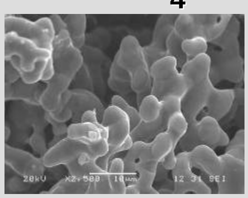
$$TiCl_4(v) + 4Na(l) \longrightarrow Ti(s) + 4NaCl(s)$$



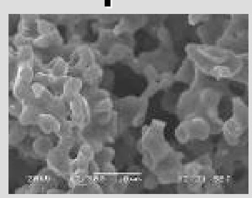
Impact of $TiCl_4$ Cost on Production Cost



Low Cost and Highly Refined $TiCl_4$ Powder Comparison



Highly Refined $TiCl_4$

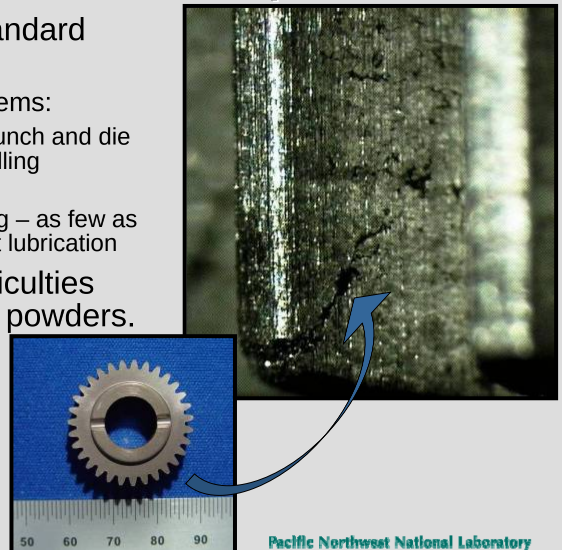


Low Cost $TiCl_4$

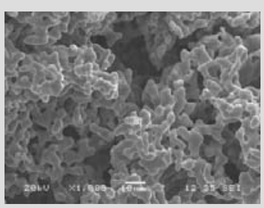
- Low cost $TiCl_4$ contained different trace impurities that were carried through powder – result of fewer refinement steps.
  - Little or no difference observed in powder morphology with $TiCl_4$ composition for ITP powder.
  - Observed higher sintered density for powders from low cost grade of $TiCl_4$.
    - Greater than 96% density for press and sintered powders
    - Observed swelling in CP grade without the impurities associated with low cost $TiCl_4$
  - Typical mechanical properties for both types – when sintered to 96+%
    - 375, 450 MPa yield and ultimate, respectively, with 8 to 15% elongation

High Production Rate Titanium Powder Compaction

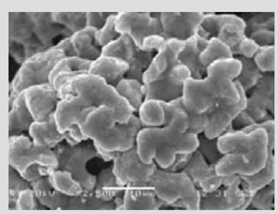
- Pressed gears in standard production die.
  - Encountered 2 problems:
    - Interference with punch and die and liner eject – Milling parameters
    - Lamination cracking – as few as 3 pressings without lubrication
- Historical Ti P/M difficulties remain with the new powders.



Milling

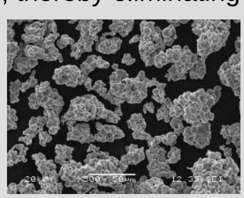


Typical open structure of powder



After milling to increase tapped density

- Milling parameters were developed to successfully compact the ligament structure improving tapped density while reducing oxygen pick up to less than 400 ppm, thereby eliminating die interference

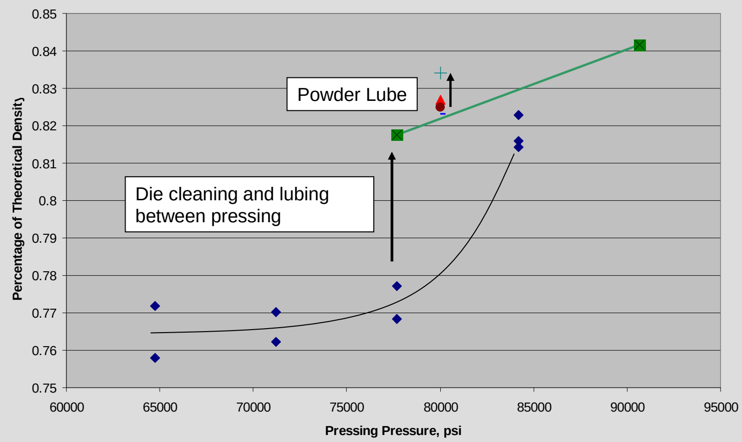


Gear Pressing Study

Lubrication Effects

31 Tooth Spur Gear Pressing

Improvement in Green Density with Die and Powder Lubrication



Technology Transfer

- Powders are not produced at PNNL commercial suppliers are being used and feedback on powders are direct
  - International Titanium Powder
  - E.I. DuPont Nemours
    - Hunter Fines – batch Na reduction
- Publication of P/M process development
  - Interaction with Western Sintering for practical high volume pressing

Conclusions – To Date

- **Titanium can significantly impact the mass of both ICE and FC vehicles.**
  - Predicted mass reductions of greater than 25% for Fuel Cell vehicles.
  - Up to 60% in Chassis alone.
- **Auto industry understands the performance benefits of titanium**
  - 14 OEMs have successfully used Ti in selected automobiles.
  - The question is implementation into high volume vehicles.
- **The implementation of Ti to the high volume automobile is limited by:**
  - **Cost of raw materials**
    - Aggressive projects throughout the world; more than 20 processes being evaluated
    - Unique opportunity in the automotive industry to establish new standards – take advantage of new processes
  - **Cost of component manufacture**
    - Move from "Rotating Grade Aerospace Titanium" Triple VAR to lower cost methods
      - Solid state consolidation – **Direct Press and Sinter**
      - Many projects looking at this – many are privately funded and ongoing

Conclusions – To Date

- **Direct Press/Sinter Powder Process Development**
  - **Sintering of the powders are impacted by small "alloying" additions.**
    - Increased sintered density observed when the onset of sintering is delayed.
    - Opportunity for tailored powder metallurgy alloys.
  - **The high die-friction observed in Ti processing can be overcome b lubrication.**
    - Instrumented die trials show lubricated Ti behaving similar to steel in die pressing
    - In-die and ad-mixed lubricants have been successfully demonstrated
    - Impurity concerns to be addressed however volatile lubricants have been successfully used both in-die and ad-mixed.
  - **Milling of the ITP powder to alternate distributions has been performed with less than 200 ppm Oxygen pick-up and sintered to greater than 96% dense**
    - Attrition milling for very short times with and without milling aid.
    - Tailored powder morphology facilitate die-fill and compaction for fine detailed components.

Next Step for FY 08

- There are 2 "New" processes for cost analysis
  - TiH_2 from "ADMA" process – Ukrainian Sponge Plant
    - DOE/IPP Project
  - DuPont – MER
    - Electrowinning process developed at MER licensed by DuPont
      - DARPA funded process
- Development of alloys for automotive use
  - Beta alloy bar stock
  - Billets to be supplied by DuPont, ADMA using ADMA, ITP and DuPont powders
- Complete lubrication development
  - Provide logical selection process and recommend lubricants to be published at MPIF June 2008.

Publications/Presentations

- Lavender CA, KS Weil, MT Smith, and Y Hovanski. 2006. "The Effect of Low-Cost TiCl4 in Titanium Powder Processing." AeroMat 2006, Seattle, WA.
- Weil KS, Y Hovanski, and CA Lavender. "Investigation of a Low-Cost TiCl4 Source for Use in Titanium Powder Synthesis via the Armstrong Process." MS&T'06 Conference, Cincinnati, OH.
- Weil S, NL Canfield, Y Hovanski, and CA Lavender. 2006. "Development of Low-Cost Titanium Powders for Automotive Applications." Presented by Curt A. Lavender (Invited) at MPIF 2006, San Diego, CA on June 19, 2006. PNNL-SA-50611.
- Lavender CA (Invited), Y Hovanski, and K Weil. 2007. "Modification and Analysis of Titanium Powders Synthesized by the Armstrong Process." MS&T07, Detroit, MI.
- Hovanski Y, CA Lavender, K Weil, and LA Jacobsen. 2007. "Net Shape Powder Metallurgy Processing Using ITP Titanium Powder." Presented by Yuri Hovanski at TMS 2007 Annual Meeting & Exhibition, Orlando, FL on Februar 27, 2007.