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Advanced *M*aterials *T*echnology

Heavy Vehicle Propulsion Materials

Development of Titanium Component Applications in Heavy-Duty Diesel Engines

Project PM 9409

Principle Investigator: John Grassi
Caterpillar Inc.
September 13, 2005

Ti Turbocharger Development

21ST CENTURY TRUCK PARTNERSHIP

21CTP

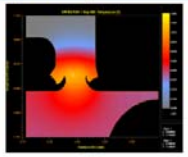
21CTP Technical Goal: Develop and demonstrate an emissions compliant engine system for Class 7-8 highway trucks that improves the engine system efficiency from ~42% today to 50% by 2010.

Project Objectives
Develop, procure and test TiAl turbine assembly on heavy duty engine to demonstrate improved transient response vs. traditional Ni-based turbine wheel.

FY 2005 Focus
Develop technology to join TiAl turbine wheel to steel shaft.

Planned Duration
March 2003 to December 2005

DOE Funding/Industry Cost Share
FY03: $500K/$500K



Left: TiAl turbine wheel welded to Ti-6Al-4V shaft with joint tensile strength higher than TiAl.
Right: FEA of the joining process is used to understand the sensitivity of the joint strength to friction welding control parameters

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Accomplishments
(1) Demonstrated joining of TiAl turbine wheel to Ti-6Al-4V shaft – April 2005
(2) Demonstrated joining of TiAl specimens to steel shaft material – June 2005
(3) Evaluated physical and mechanical properties of candidate TiAl alloys – July 2005

Significant Future Milestones
(1) Demonstrate joining of TiAl turbine wheel to steel shaft. (9-05) **(2)** Perform engine test on TiAl turbine assembly to compare response and performance to Ni-based turbine assembly. (12-05)

Project ID/Agreement ID	Program Structure	Sub-Program Element	R&D Phase	Date
PM_9409	Materials Technology	HV Propulsion Materials	Applied Research	8-12-05

Objectives

Develop and demonstrate a high-strength, lightweight Titanium Aluminide (TiAl) turbine for a heavy duty diesel engine. The unique material properties of TiAl will enable the next generation of turbocharger designs to have:

- Improved thermal efficiency
- Lower mass / inertia
- Increased transient response

Successful development will be achieved by:

- Selecting the appropriate TiAl alloy and procuring high-quality TiAl castings/forgings.
- Developing robust TiAl joining technology to deliver prototype TiAl turbine assemblies for engine testing.
- Demonstrating improved thermal efficiency and transient response in engine test.
- Establishing a TiAl material property database to be used as a design tool and for improving next generation TiAl turbine design.

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Relevance to 21CT Goals

Partnership Goal

"Develop and demonstrate an emissions compliant engine system for Class 7-8 highway trucks that improves the engine system fuel efficiency by 20% (from approximately 42% thermal efficiency today to 50%) by 2010."

Aligned Program Objective

Unique TiAl turbine design will **increase energy efficiency (BSFC~2%)**, improve transient response (~22%) while meeting all EPA emission regulations.

Technology Transfer

Engaged collaborators

Caterpillar Inc.
- Advanced Materials Technology
- Advanced Production Technology
- Air Systems Design Group
- Engine Research
- Lafeyette/Mossville Engine Centers

Oak Ridge National Laboratory

OEM Suppliers

Commercialization Pathway

Initial Development: **Prime path** for select off-highway applications in 2008. Experience with low volume product under harsh conditions will encourage future high volume (on-highway) applications.

Future Development: Aligned to **Caterpillar ACERT** engines for on-highway truck applications for 2010.

Approach

Finalize turbine wheel component design

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Procure turbine wheel castings

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Perform FEA to study joining process and understand sensitivity of joint strength to process control parameters

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Friction welding joint optimization

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Deliver "engine test ready" shafted wheel

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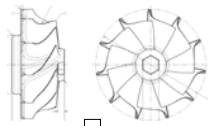
Perform engine test with TiAl turbine assembly to demonstrate improved thermal efficiency and response time

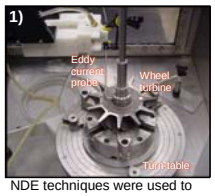


Caterpillar's ACERT Technology Truck Engines

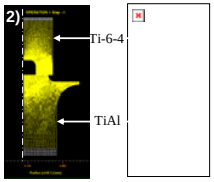
Technical Accomplishments

Wheel to Shaft Joint Development

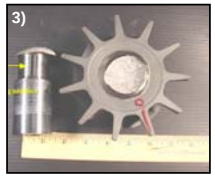
1) With the assistance of ultrasonic NDE, identified the critical factors that cause welding cracks.
2) Optimized joint geometry and welding parameters via FEA analysis to produce a crack-free joint.
3) Demonstrated friction weld joint of TiAl turbine to Ti-6Al-4V with joint tensile strength up to 570MPa.



NDE techniques were used to identify joining interface defects and radial cracks



FEA used to study the effect of geometry constraint on the joint quality

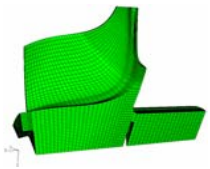


Friction welded TiAl turbine wheel failed ~20 mm away from the welding interface in tensile test

Technical Accomplishments

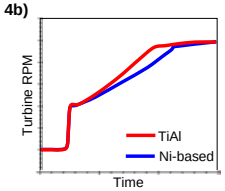
Component Characterization

4a)



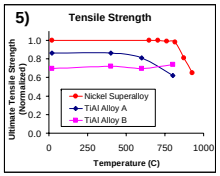
Finite element model of TiAl turbine

4b)



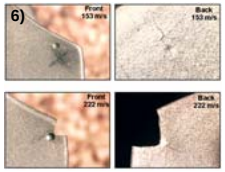
Normalized response time of TiAl vs. Ni-based turbine

5)



Comparison of tensile strength of TiAl and Ni-based alloy

6)



Micrographs of TiAl blade foreign object damage failure

4) Completed FEA analysis of TiAl turbine; results demonstrated 22% transient response improvement and 50% max stress reduction vs. Ni-based turbine.

5) Evaluated physical and mechanical properties of TiAl alloys to establish a database of TiAl material properties for design guidance.

6) Foreign object damage testing revealed that the primary failure mode of ballistic impact is localized backface cracking; deemed acceptable for use in a turbine assembly.

Future Work

- Validate wheel/shaft joint technology (friction welding) by delivering shafted wheel with robust joint strength.
- Perform engine test with TiAl turbine assembly to demonstrate improved thermal efficiency and response time.
- Complete TiAl material property database
  - Conduct creep tests at Oak Ridge National Laboratory
  - Conduct environmental resistance tests at Oak Ridge National Laboratory
  - Conduct thermo-mechanical fatigue tests at Caterpillar
- Implement in high volume on-highway applications by leveraging experience with off-highway application.