Durability of ACERT™ Engine Components

H.-T. Lin, T. Kirkland, and A. A. Wereszczak
M. Kass, R. M. Wagner, and N. Domingo
Oak Ridge National Laboratory

J. A. Jenson and N. Phillips
Caterpillar Inc.

May 21, 2009, Arlington, Virginia

Project ID
#pmp_11_lin

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

- Start – Oct 2007
- Finish – Sept 2011
- ~ 25% Complete

Barriers*

- Light weight, high strength materials will be required for structural components to meet the 55% efficiency goal.
- Develop hot-section component to substantially reduce parasitic energy losses.
- Thermal control is very critical in LTC engines because LTC processes are very sensitive to temperature.

Budget

- Total project funding
  - DOE – $800K
- Funding received in FY08
  - $200K
- Funding so far for FY09
  - $91K

Target

Enable HD engine efficiency of 55% and life greater than 1 million miles by 2012

Partners

- Caterpillar Inc.
- Argonne National Lab

*FreedomCar and Vehicle Technologies Program, Multi-year Program Plan, 2006-2011, p. 2.4-8&9

Objectives

- Support ORNL-Caterpillar CRADA for materials-enabled high-efficiency diesel engine.
- Indentify the effect of HDD environment on the degradation processes of materials and components.
- Develop test methodology to characterize mechanical properties of complex-shaped HDD components.
- Characterize mechanical properties of high temperature light weight valves designed and implemented for heavy duty diesel (HDD) engines.

Materials-Enabled Technologies for High Efficiency Diesel Engines: CRADA

This CRADA makes use of engine/combustion and materials expertise at Caterpillar and ORNL to provide new insight into the integration of these technologies through a materials-by-design approach to high temperature, high pressure engine operation.

- **Engine & tool**
- **Identification & prioritization of materials R&D needs**
- **Technical & hardware support**

CAT C15 ACERT™ Engine in ORNL Engine Cell

- **Engine performance studies**
- **Advanced diagnostics & combustion analysis**
- **Materials characterization & modeling**

CATERPILLAR

OAK RIDGE National Laboratory

Materials & Engines approach provides a more complete understanding to better improve combustion, thermal management, emissions & cost reductions.

OAK RIDGE National Laboratory

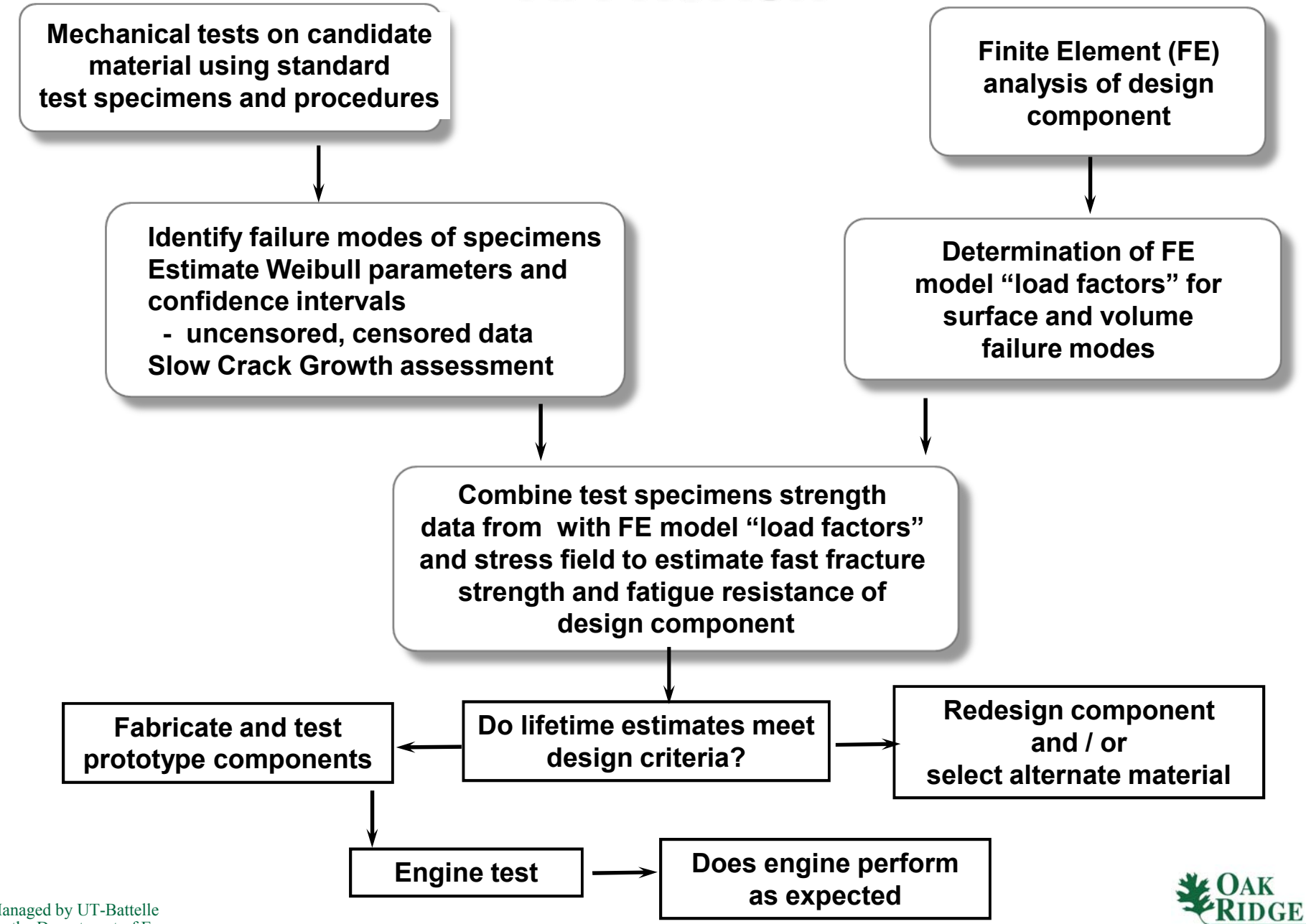
Milestones

Sept 2008 – Milestone: mechanical testing and analysis of prototype silicon nitride and TiAl valves after natural gas engine field test (completed).

Sept 2009 - Milestone: complete thermal cycle testing on coated coupons to understand the failure mechanisms.

Sept 2010 – Milestone: testing and analysis of a prototype ACERT™ component

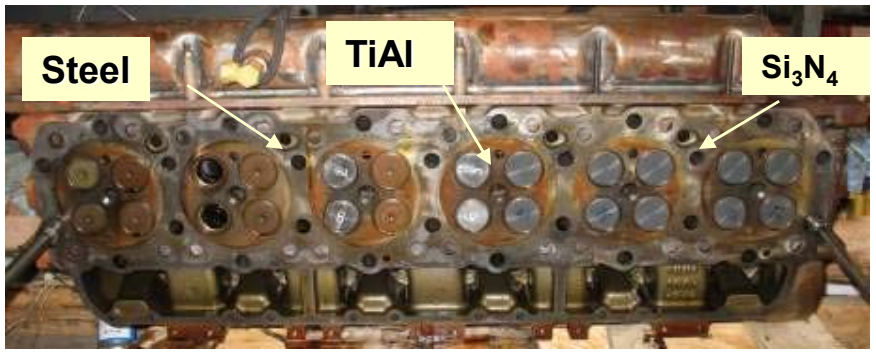
APPROACH



Accomplishments

Engine field test verified the component design and life prediction model for advanced light-weight valves

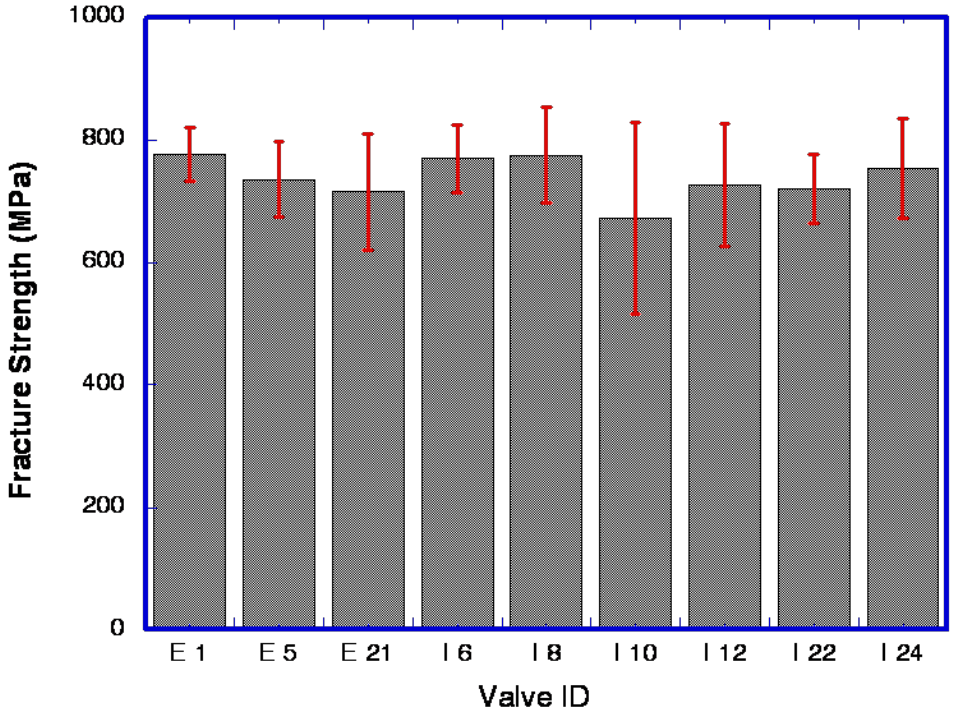
Valves tested:
Silicon nitride: Kyocera SN235P
TiAl: HOW45
Inconel: Nimonic 80A & 90
(current production materials)

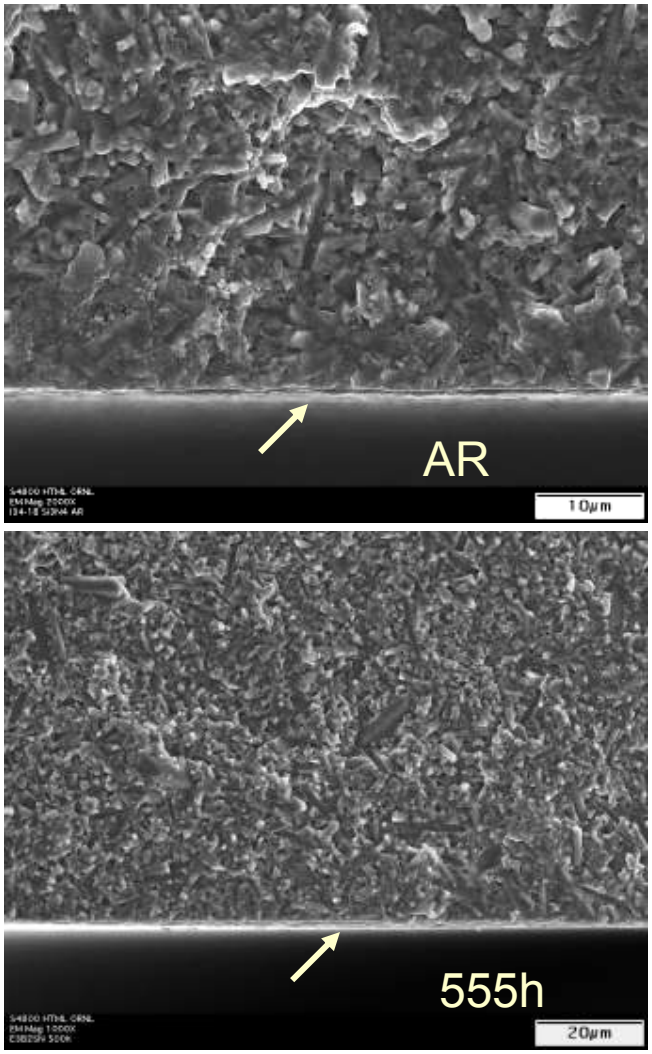


After 555h test at Cat G3406 natural gas engine the field test was discontinued

Accomplishments (continued)

Data provides insight into the environmental effect on the mechanical reliability of TiAl and Si_3N_4 engine-tested valves



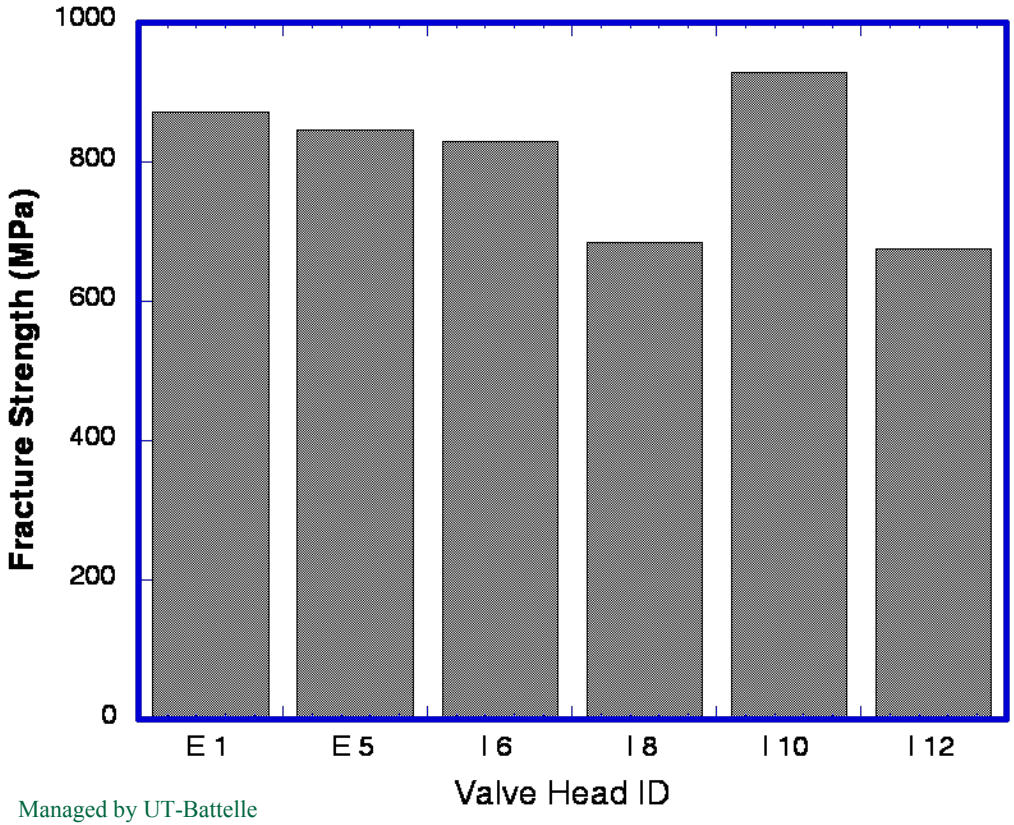


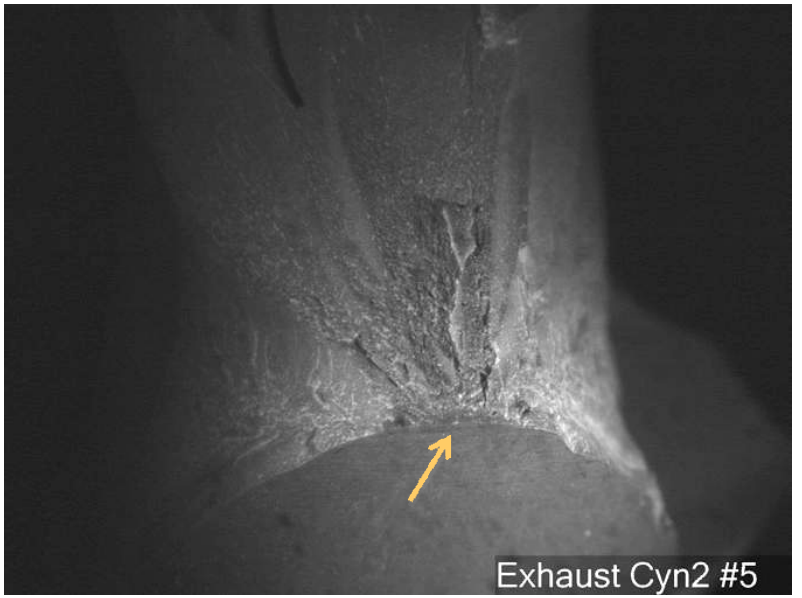
No mechanical strength loss for valve stem after 555 h engine test

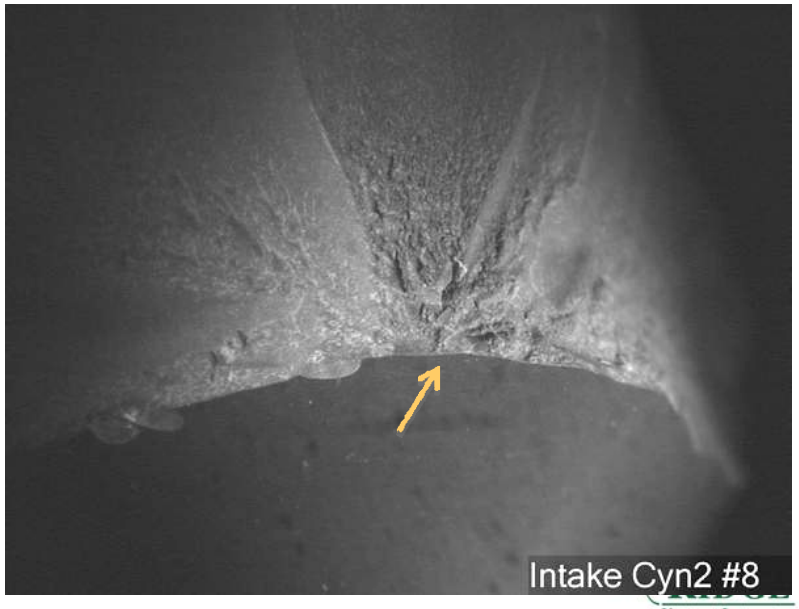
OAK RIDGE National Laboratory

Accomplishments (continued)

Fracture mostly initiated at the original machining flaw (groove) region. There is little or no environmental effect on the mechanical performance of Si_3N_4 valves after 555h engine test.

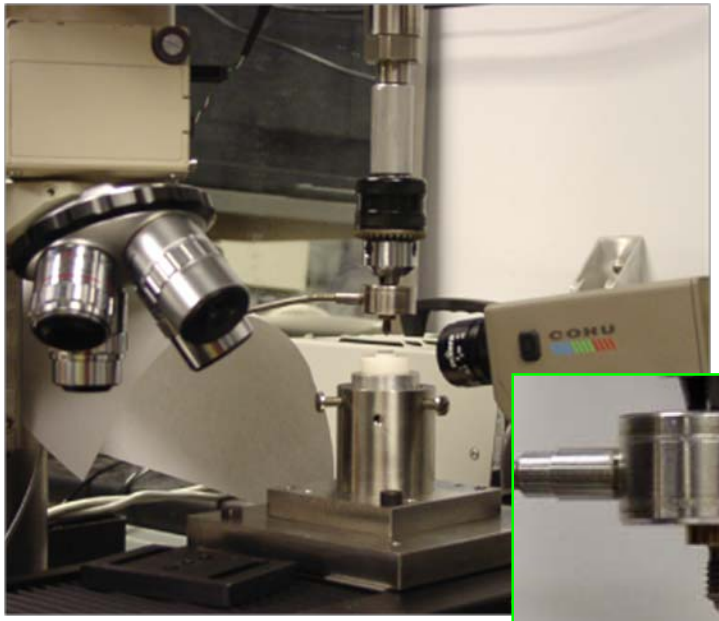


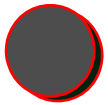




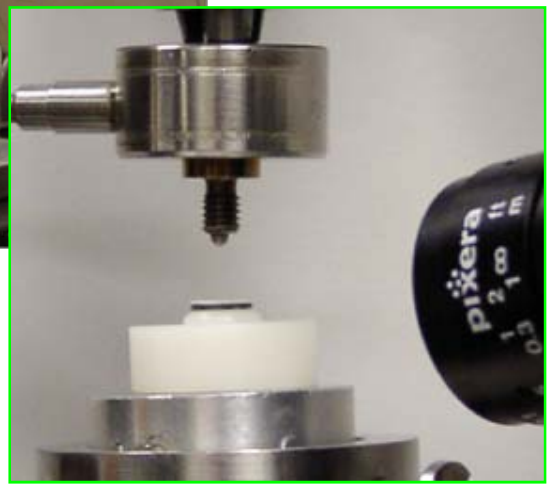
Accomplishments (continued)

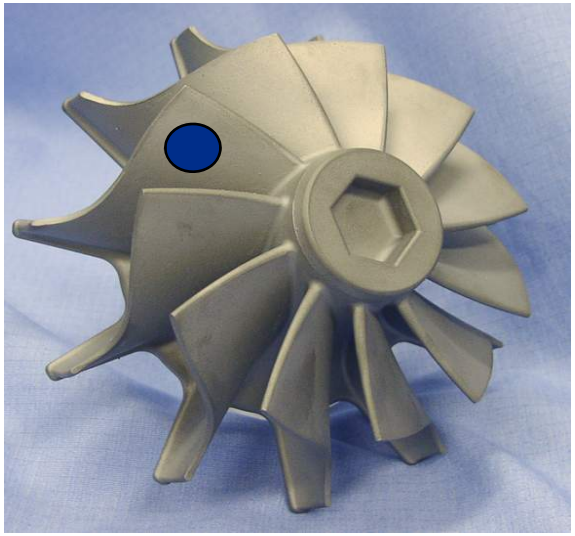
- Determine the mechanical properties of airfoils from TiAl turbo wheel.
- Provide “real” component database for verification of design and life prediction.





Dia. ~ 10 mm
t = 0.5 mm



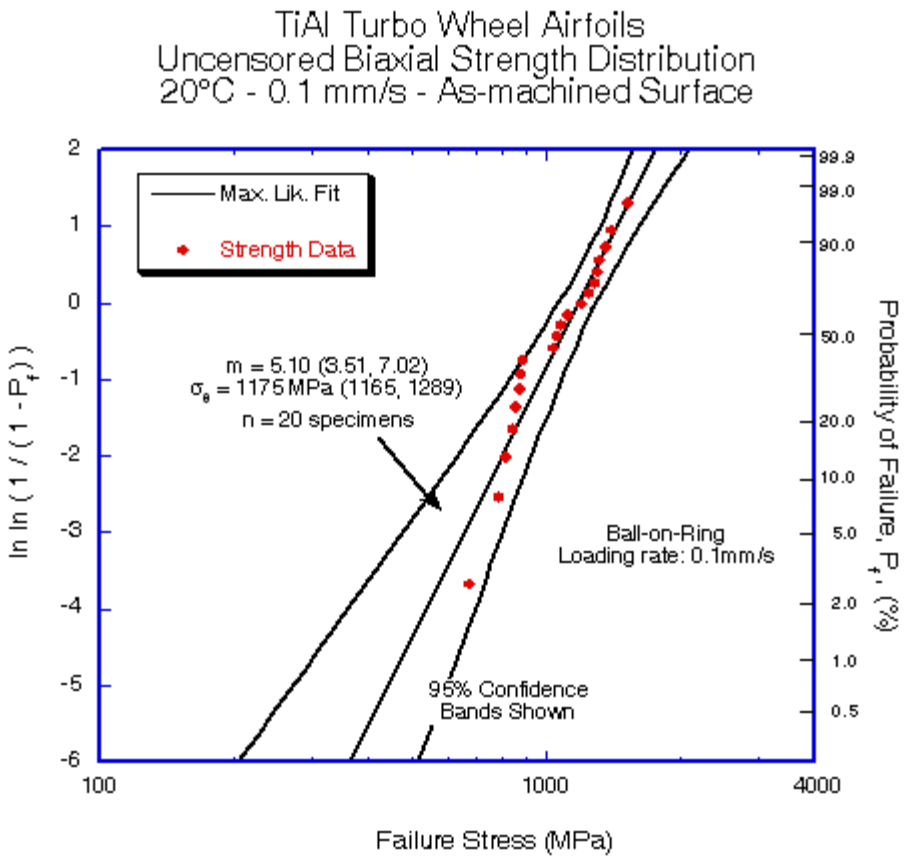


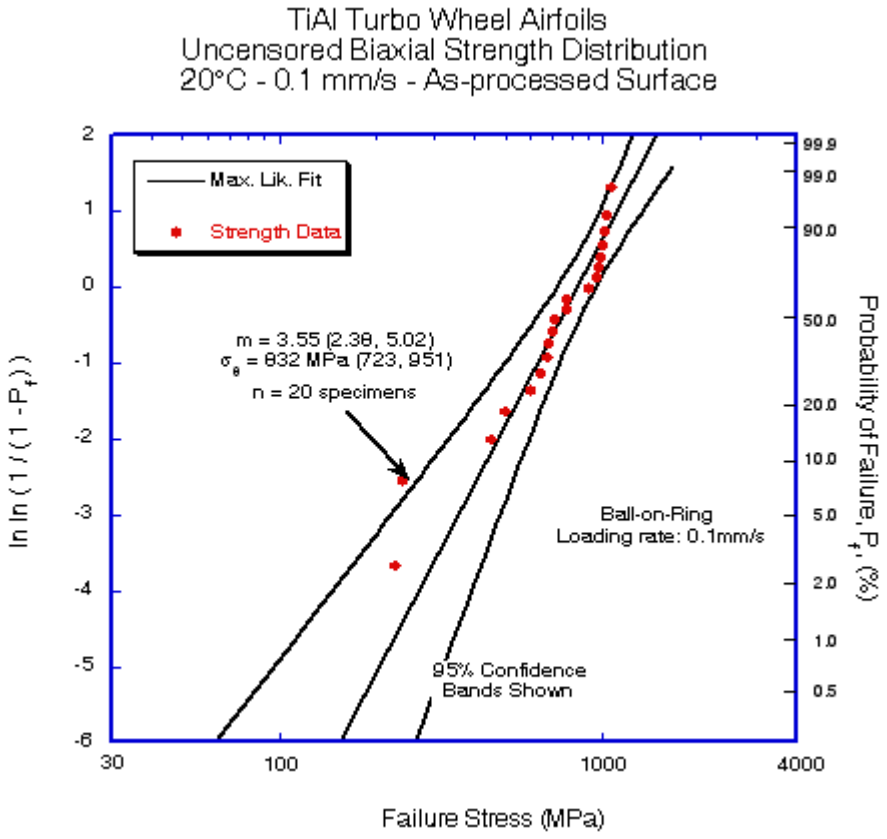
CATERPILLAR

Controlled by personal computer with LabView program

Accomplishments (continued)

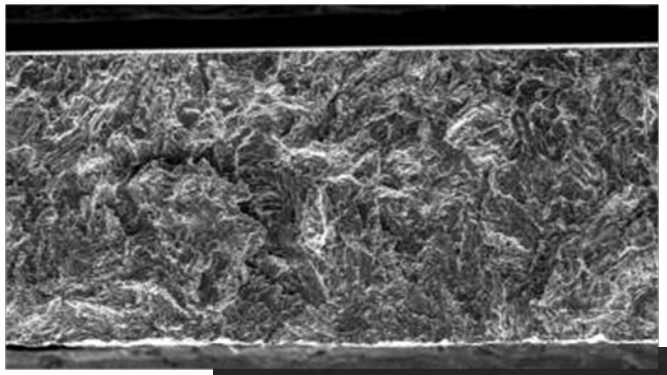
- **Fractography has been conducted on tested specimens.**
- **The strength of specimens with as-processed surface is ~ 30% lower than those with as-machined surface.**

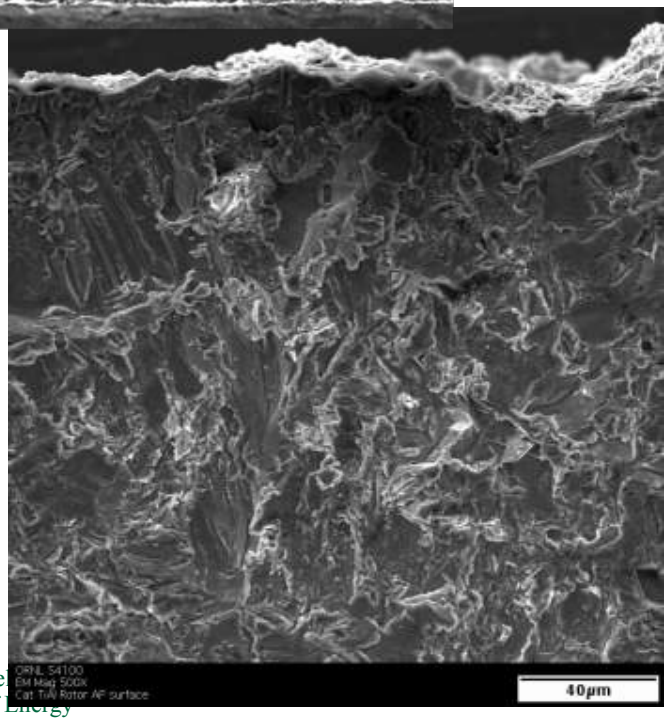




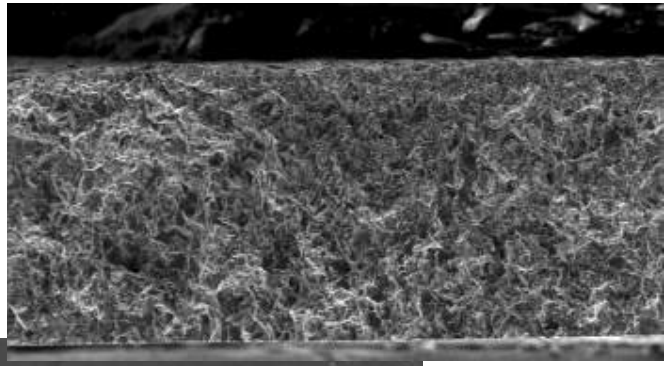
Accomplishment (continued)

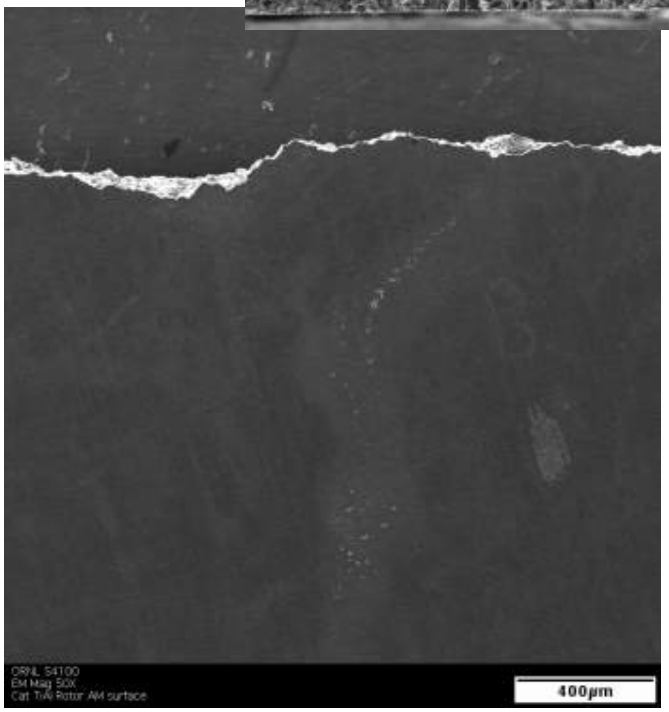
- **The surface roughness feature contributed to the lower fracture strength measured for samples with as-received surface**





Ra=
0.33 µm

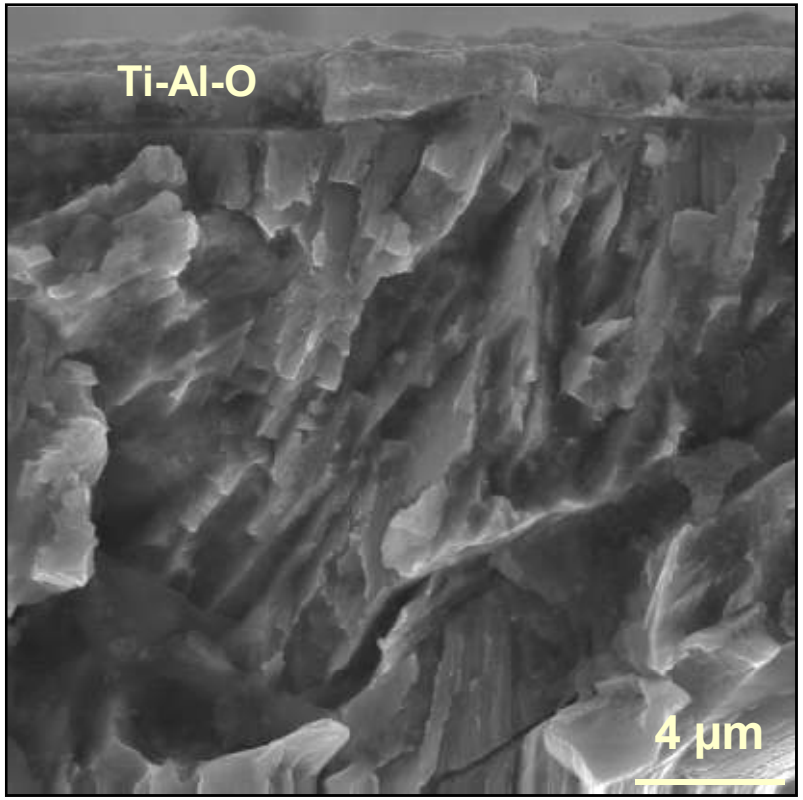


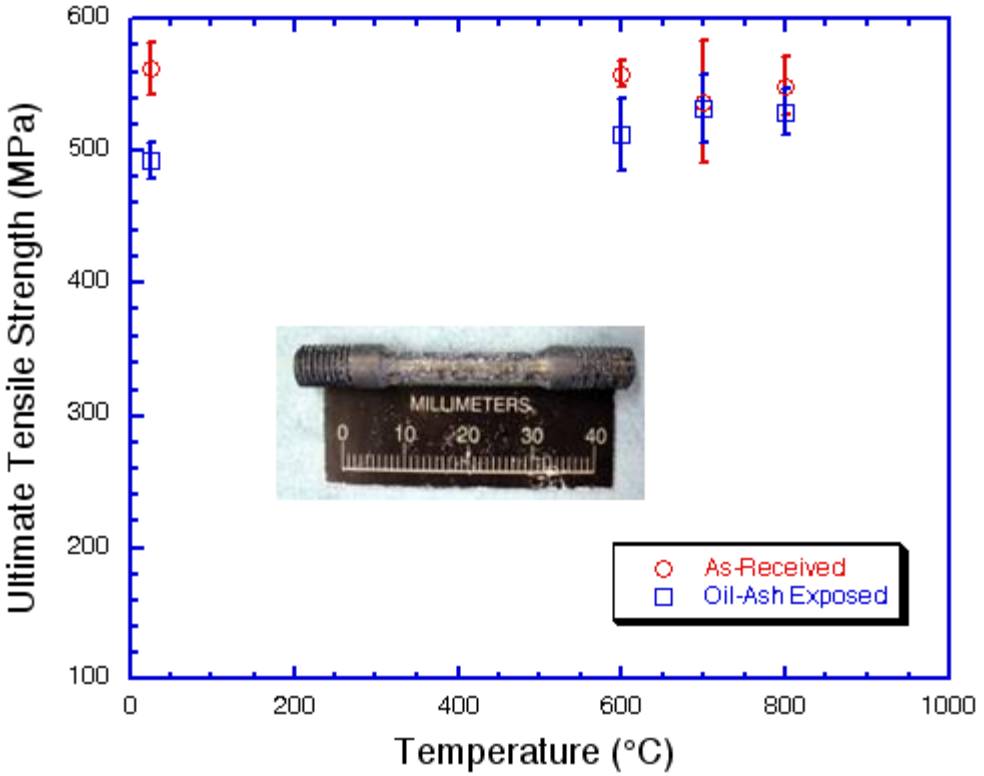


Ra=
3.28 µm

Accomplishments (continued)

- **Only minor decrease in tensile mechanical strength of TiAl alloy after oil immersion test @ 780°C/48h**





Difference in UTS decreases with increasing test temperature probably due to surface healing by oxidation

Materials Evaluation Research Plan – Future Work

- Selected material coating has the potential to:
  - Reduce thermal losses
  - Reduce manufacturing cost
  - Improve durability
- Evaluate the performance of a coated component in exhaust system (initial location is to be downstream of turbo)

  Variables include:
  - Temperature
  - Exhaust flow rate
  - Transients
  - Exhaust chemistry
- Analyze component for structural integrity
  - NDE
  - Microstructural analyses
- Temperature data inputted to model to assess thermal management potential and identify locations for additional modifications
- Expand research plan to additional components & materials

Summary

- A protocol was developed for testing prototype engine components in nature gas engine and post-test analysis.
- A 555h NG engine field test with high temperature light weight TiAl and silicon nitride valves was completed. The termination of engine testing was due to the failure of steel valve keepers.
- Characterization of mechanical properties and microstructure of engine tested valves was completed. No degradation was observed based on mechanical and microstructure results that confirmed the life prediction model.
- Mechanical results indicated the airfoil specimens of TiAl turbo wheel with as-processed surface exhibited 30% lower strength than those with as-machined surface.
- Tensile mechanical strength measurements showed no environmental effect on the TiAl alloy after exposure to simulated engine environment.
- A 3-years ORNL-Caterpillar CRADA was officially approved and the kick-off meeting was held at Oak Ridge National Laboratory.