CRADA NFE-08-01671 – Materials for Advanced Turbocharger Design

Agreement - 17257

PI – Philip J. Maziasz, ORNL and Marc Wilson, Honeywell

Oral – June 19, 2014

Project Area – Materials for Combustion Systems/High Efficiency Engines

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

Timeline
• Project began – September, 2009
• Project ends – September, 2014
• Project is >75% complete

Budget
• Total Project Funding
  • DOE Share – 50%
  • Honeywell – 50%
• FY12 Funding - $300,000
• FY13 Funding - $0
• FY14 Funding – $150,000

Barriers
• Barriers addressed include:
  • Difficulty in simultaneously increasing efficiency and reducing emissions
  • HECC Technologies increase exhaust temperatures for turbochargers

Partners
• Honeywell suppliers for turbocharger components
• Engine customers for turbochargers (LD and HD engines)
This CRADA project is relevant to a key technical gap in Propulsion Materials that supports the following Advanced Combustion Engine goal:

**2015 Commercial Engine – Improve Efficiency by 20% over 2009 baseline efficiency**

**Turbocharging improves fuel efficiency particularly in gasoline engines**

**Technical Objective** – Higher temperatures (>750°C, diesel, >950°C gasoline) exceed the strength and temperature capability of current materials, particularly cast-iron for turbocharger housings

**Impact** – Turbocharger housing and other components with more temperature capability and strength will enable higher, sustained operating temperatures. Stainless steel turbo-housings will also reduce weight and retain exhaust heat relative to cast-irons
Approach - Caterpillar Commercialized **CF8C-Plus steel** for the CRS component that are on all heavy-duty highway truck diesel engines since 2007 (Oct, 2006)

- **CF8C-Plus steel**
- **SiMo Cast-iron**

Over 500 tons of CF8C-Plus cast for CRS application (no failures, some >6 y)

- Exhaust combustor (turbo exhaust + injected fuel) to clean out particulate filters: very high temperature and rapid cycling conditions
## Approach – Cast Keel Bars or Blocks for Properties Testing

<table>
<thead>
<tr>
<th>alloy</th>
<th>Cr</th>
<th>Ni</th>
<th>Mn</th>
<th>Mo</th>
<th>Nb</th>
<th>C</th>
<th>N</th>
<th>Si</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF8C-Plus</td>
<td>19.1</td>
<td>12.5</td>
<td>3.5</td>
<td>0.35</td>
<td>0.94</td>
<td>0.09</td>
<td>0.24</td>
<td>0.6</td>
<td>bal</td>
</tr>
<tr>
<td>HK30-Nb</td>
<td>25.2</td>
<td>19.4</td>
<td>1.2</td>
<td>0.27</td>
<td>1.2</td>
<td>0.30</td>
<td>1.6</td>
<td>bal</td>
<td></td>
</tr>
</tbody>
</table>
Approach – Follow Honeywell Requirements for Qualifying Turbocharger Materials

Phase 1
- Screening
  - J-MAT-PRO simulation tool
  - Materials Engineering

Phase 2
- Thermal
- Physical
- Monotonic
  - Room Temp. Tensile
  - Elevated Temp. Tensile

Phase 3
- Fatigue
- Creep
- Oxidation
- Damping
  - Strain/Stress controlled LCF
  - Stress Controlled HCF

Phase 4
- Interaction
  - Thermo-Mech
  - Fatigue
  - Fatigue-Creep
  - Fatigue-Oxidation

- Thermal
  - Thermal Expansion
  - Heat Capacity
  - Thermal Conductivity
  - Thermal Diffusivity

- Physical
  - Density
  - Poisson’s Ratio
  - Young’s Modulus

- Monotonic
  - Room Temp. Tensile
  - Elevated Temp. Tensile
Milestones

- FY2013, Q1 – complete neutron-scattering residual-stress measurements on wheel/shaft assemblies with stress-relief heat-treatments (Dec, 2012, complete)

- FY2013, Q3 – begin creep-tests of cast CF8C-Plus stainless steels to facilitate gasoline turbocharger applications (July, 2013, complete)

- FY2014, Q1 – Complete diesel engine exhaust testing of CF8C-Plus steel at 800C (Dec. 2013, complete)

- FY2014, Q2 – Evaluate oxidation resistance of CF8C-Plus tested in diesel exhaust environment (Mar. 2014, complete)

- FY2014, Q3 – Assist Honeywell in indentifying appropriate foundries for prototyping CF8C-Plus housings (June 2014, on track)
Technical Accomplishments – Upgrade Turbo-Housing to Cast Stainless Steel

ORNL developed CF8C-Plus cast stainless steel with more strength than HK30Nb stainless alloy > 750°C.

Both have ten times more strength than SiMo cast-iron above 500-600°C

Current SiMo cast-iron turbocharger housing for diesel engine product
Technical Accomplishments – Upgrade Turbo-Housing to Cast Stainless Steel for More High-Temperature Creep Resistance

- CF8C-Plus cast stainless steel has significantly better creep-resistance than SiMo and Ni-resist cast irons at 700-900°C

- CF8C-Plus stainless steel cost is about 33% less than HK30-Nb alloy
Technical Accomplishment – Oxidation Testing in a Diesel Exhaust Environment at 800C

Preliminary tests indicated a substantially lower rate of oxidation after testing in actual diesel exhaust vs. laboratory air + 10% water vapor at 800C.
Technical Accomplishment - Physical Properties – Thermal Expansion

CTE Data for CF8C-Plus and HK-30Nb Steels

CTE (alpha/K)

Temperature (C)

Heat 1
N277
HK-30Nb
Technical Accomplishment - Physical Properties – Thermal Conductivity

Thermal Conductivity Data for CF8C-Plus and HK-30Nb Steels

- **Thermal Conductivity (W/mK)**
- **Temperature (C)**

Legend:
- **heat 1**
- **N-277**
- **HK-30+Nb**
What’s Next - High Temperature Material Testing

Material testing

- LCF Iso-Thermal
- Thermo Mechanical Fatigue
- Creep/ Stress Relaxation
- Fatigue with Dwell
- Creep-Fatigue-Oxidation
Issues and Barriers

• Decreased funding with increased Honeywell need for expensive testing (fatigue, creep, TMF)

• Upgrade of creep machines and fatigue machines after extended high temperature testing

• Installation of new diesel exhaust facility at ORNL

• Honeywell CRADA needs to be extended for 2 more years before September, 2014
Summary

- **Relevance** – Turbocharging improves fuel efficiency of gasoline engine vehicles

- **Approach/Strategy** – Work with Honeywell phased approach to qualifying CF8C-Plus steel for turbochargers

- **Accomplishments** – Completed Phase 1 testing creep, fatigue and thermal fatigue qualifying CF8C-Plus steel

- **Collaborations** – SF&E, Honeywell and potential engine customers (Caterpillar, Ford, etc.)

- **Proposed Future Work** – Phase 2 – 4 testing of CF8C-Plus, particularly fatigue and creep testing.