Mechanisms of Oxidation-Enhanced Wear in Diesel Exhaust Valves

(Friction and Wear Reduction)

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U.S. DEPARTMENT OF ENERGY

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OAK RIDGE National Laboratory

Overview

Timeline

- Project start date: October 2006
- Project end date: September 2009
- Percent complete: 80%

Budget

- Total project funding
  - DOE: 100%
- Funding for FY08: $ 200K
- Funding for FY09: $ 200K
- Funding for FY10: none

Barriers

Barriers addressed:

- Improve engine system fuel efficiency for Class 7-8 trucks by 20% by 2010.
- Reduce wear (leakage) around valve seats to improve diesel engine efficiency.

Partners

- Informal collaboration with Caterpillar (sharing results and providing valves for testing)
- Project lead: ORNL

Project Objectives

FY 2008-9 Objectives:

- To develop a comprehensive understanding of the fundamental interactions between mechanical wear and corrosion processes that operate in diesel engine exhaust valve/seat environments
- To extend the knowledge of oxidation-affected wear to model the surface degradation that occurs during valve seat recession and facilitate materials selection for high-temperature service.

Relevance to the OVT Heavy Vehicles Program:

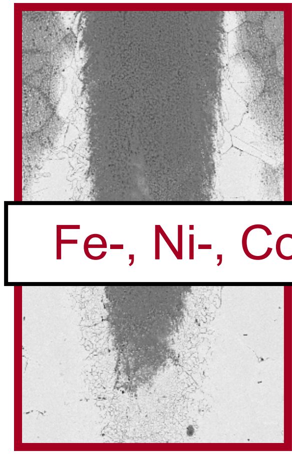
- Support the informed selection of exhaust valve alloys that resist wear and oxidation under high-temperature operating conditions in engines.
- Wear of valve sealing surfaces can increase emissions and reduce cylinder pressure leading to a loss in engine performance.

Milestones for FY 2009
(Final project year)

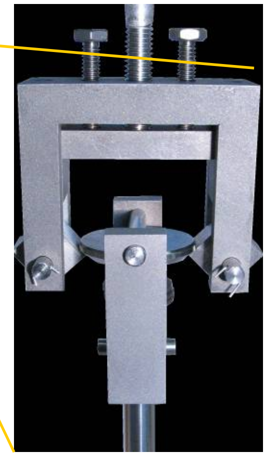
Month / Year	Milestone
May / 2009	**Experimental**: Using the custom-designed, high temperature repetitive impact system (HTRI), conduct tests to investigate how the surfaces of Ni-, Co-, and Fe-based alloys react to oxidation, depending on the type of wear to which they are subjected in valve seats.
Aug / 2009	**Model Development**: Integrate an understanding of wear-oxidation effects with the processes involved in valve recession and propose a model to explain these effects in alloys of interest, including commercial valve materials.
Sep / 2009	**Final Report**: Complete experimental and modeling studies of the effects of mechanical damage on the oxidation of high-performance alloy surfaces at diesel engine exhaust valve operating temperatures and provide design guidance for the selection of valve alloys.

Overall Approach

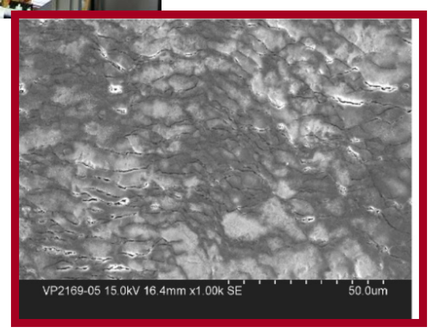
Experimental



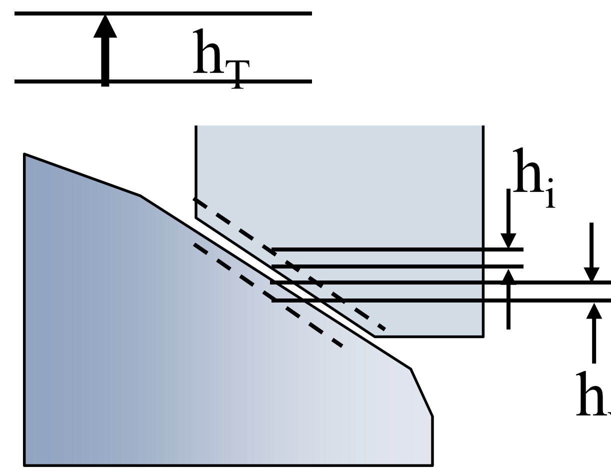
Fe-, Ni-, Co-alloys



- ❑ Oxide layer ‘healing’
- ❑ Built a high-temperature impact wear rig (uses either valves or simple coupons)
- ❑ Analysis of wear / oxidation microstructures of alloys



Modeling

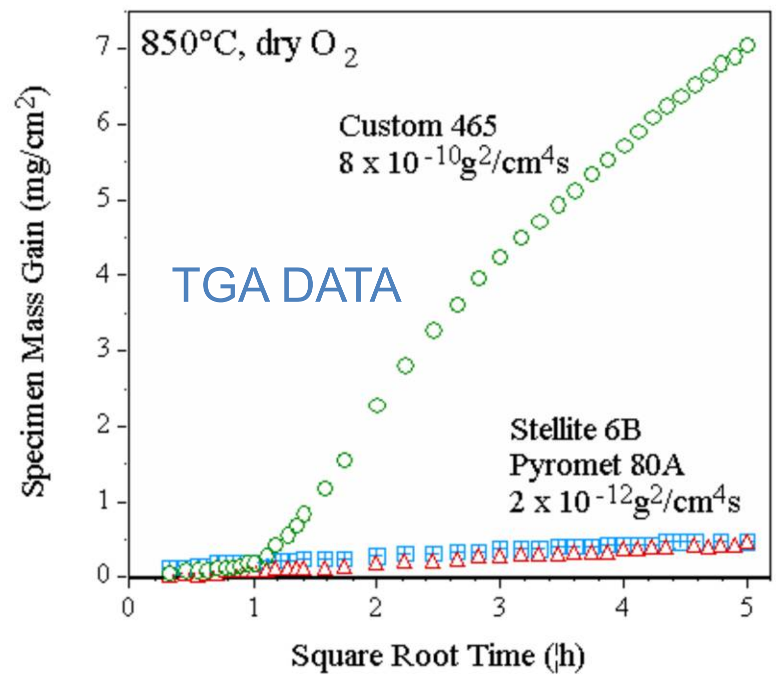


Combined plastic deformation, wear, and oxidation on both valve and seat surfaces

Material Selection

Technical Progress and Results (1/5)

- **Alloy selection**:
  - •(a) Pyromet 31V (diesel engine exhaust valve material)
  - •(b) Custom 465™ (Fe-based alloy)
  - •(c) Pyromet 80A™(Ni-based alloy)
  - •(d) Stellite 6B™(Co-based alloy)
- **Baseline oxidation rate studies** (conducted by B. A. Pint, ORNL): Static oxidation rates (TGA), oxide scale characterization.



Oxide scales formed after 25 h exposure at 850° C

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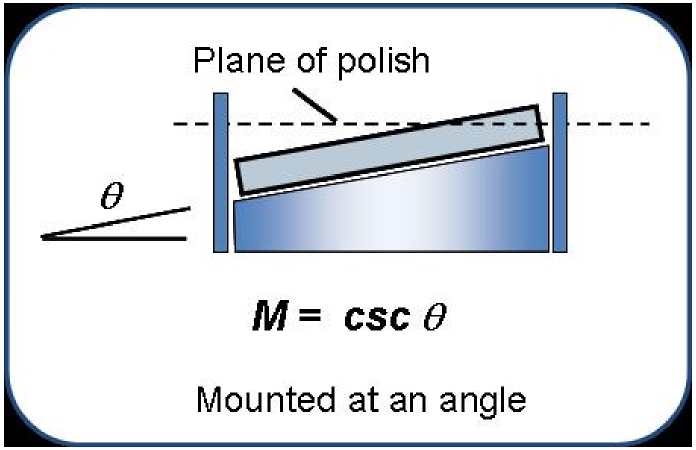
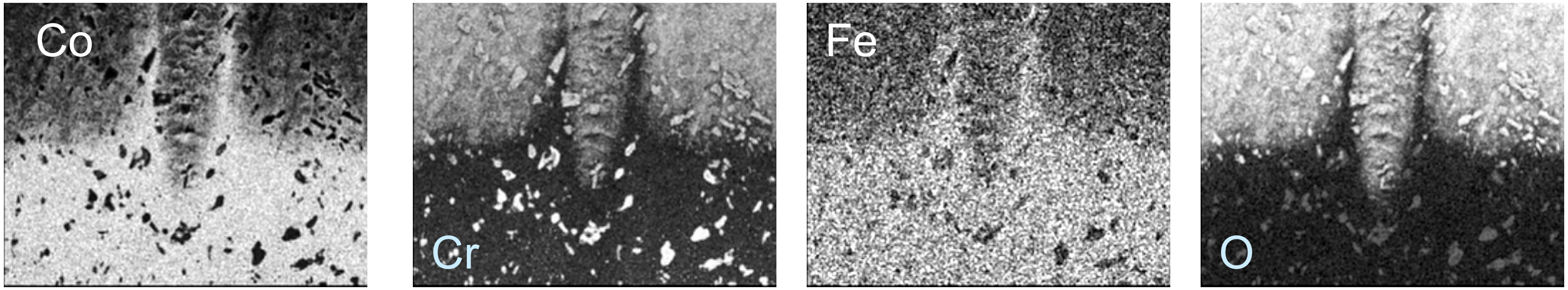
Technical Progress and Results (2/5)

- **Oxide scale 'healing' experiments**
  - Polish surfaces of Fe, Ni, Co alloys
  - Pre-oxidize at 850° C 2 hrs
  - Scratch with a diamond stylus
  - Expose for 4 more hours at 850° C
  - Cross-section (taper polish) and study composition of the oxides on and off the scales



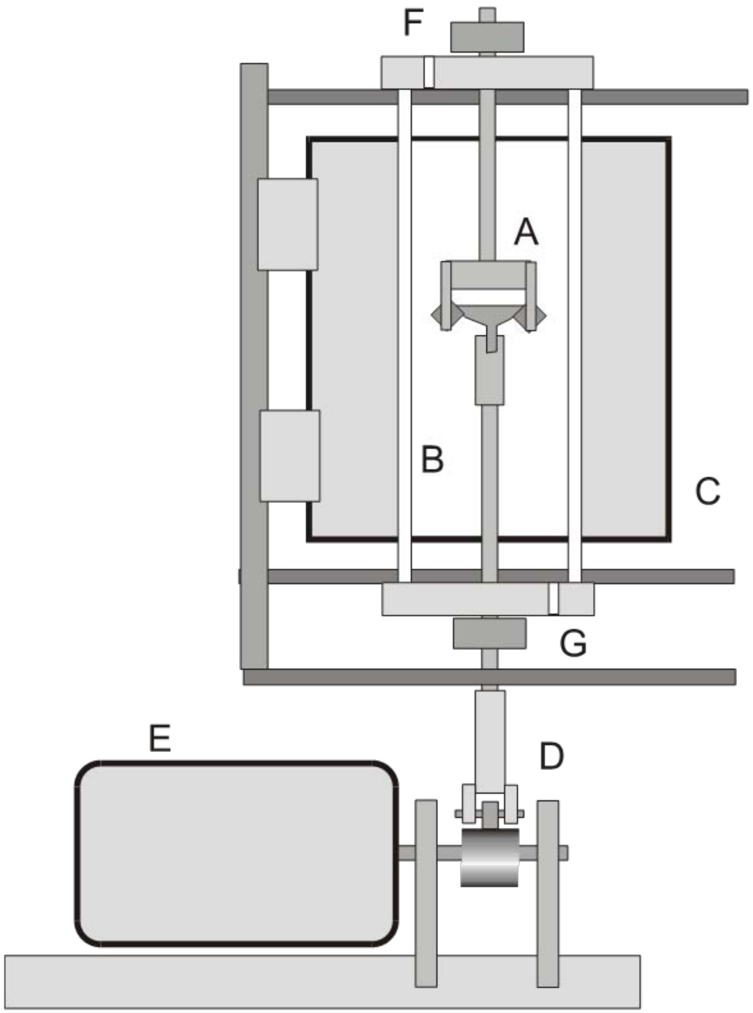
- **Results:** Scratch grooves form different oxide compositions than surfaces on either side of the scratch

X-ray composition maps of taper-polished scratches on the Co-alloy (Stellite 6B™)

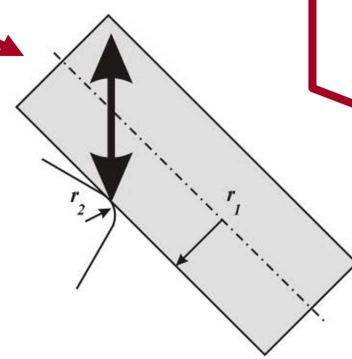


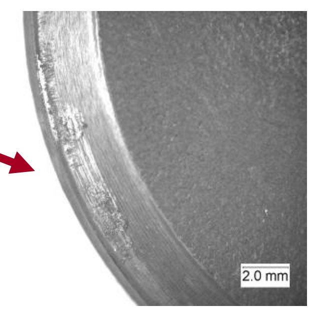
Hitachi 3400N environmental SEM, EDX mode

Technical Accomplishments (3/5)



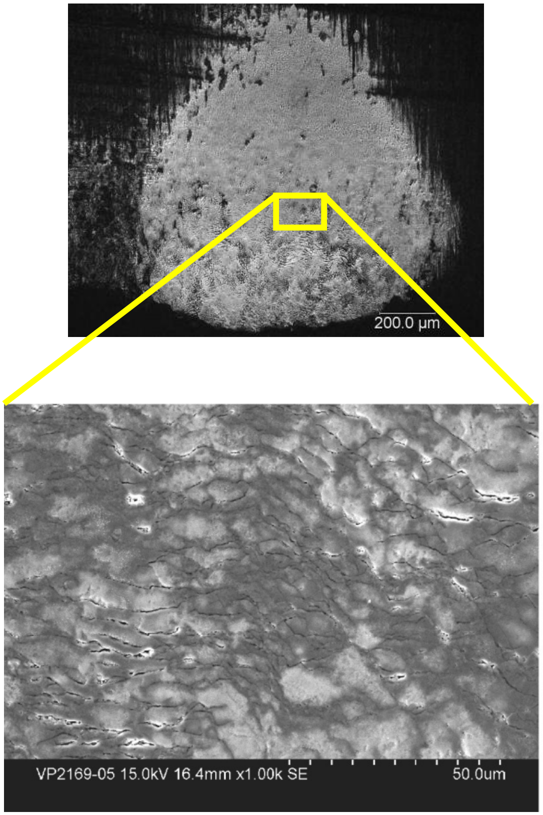
- Repetitive Impact Experiments at High Temperature
- Temperatures up to 850° C in air
- Combined impact plus slip, as in a valve
- Two contact geometries (45 degree impacts)
  - Simple cylinders against block corners
  - Actual valve 'tulips' against block faces





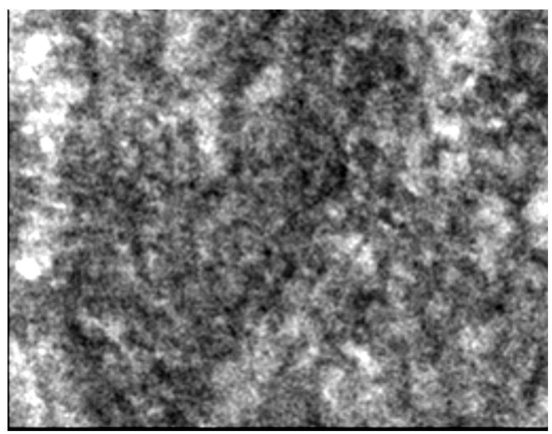
Technical Accomplishments (4/5)

- Observations of repetitive impact damage and oxidation products (Cylinders-on-blocks configuration)
- Compositional mapping and metallographic sectioning
- Indentation hardness of mechanically-mixed layers consisting of metal with oxide
- Comparison of Co-, Ni-, and valve alloy surfaces under high temperature conditions

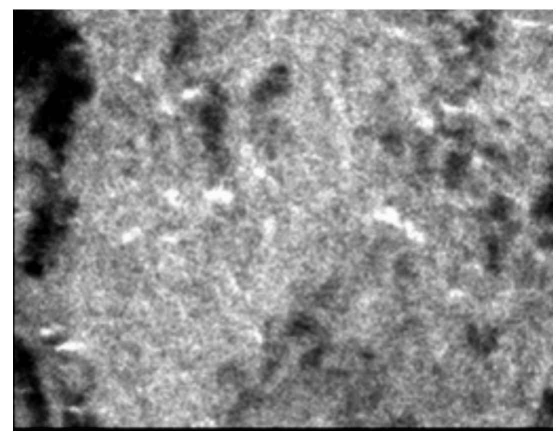


SEM image

(Twin cylinders-on-blocks geometry)

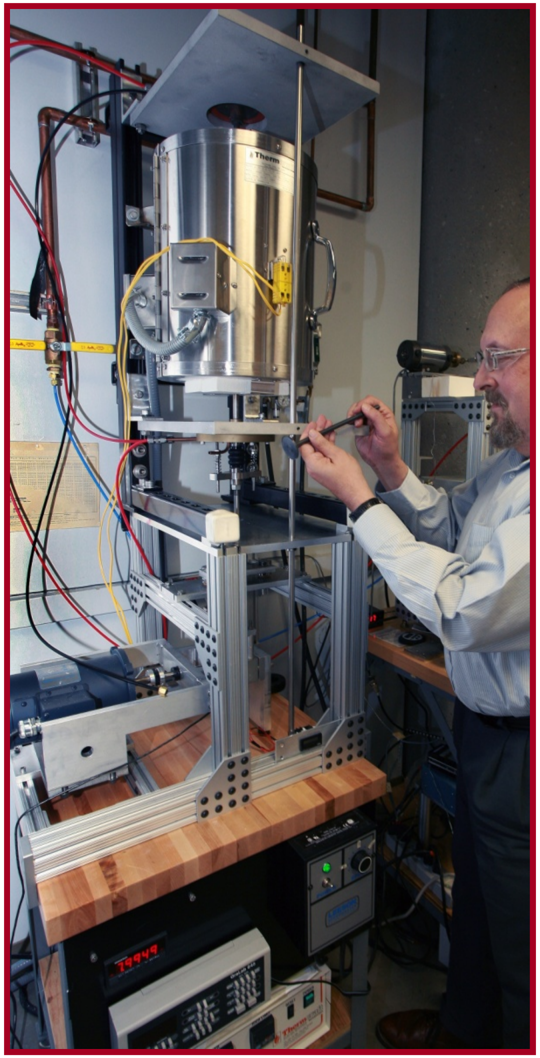


Cr elemental distribution

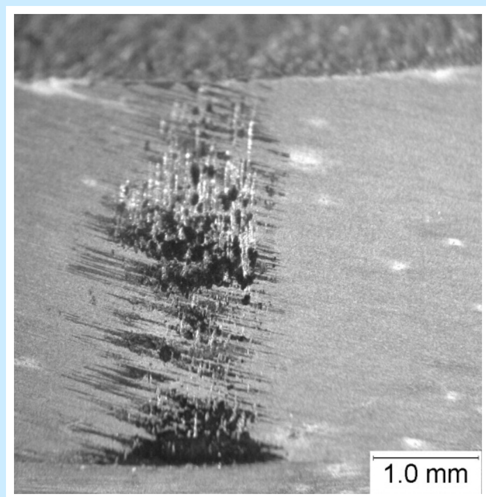


Ni elemental distribution

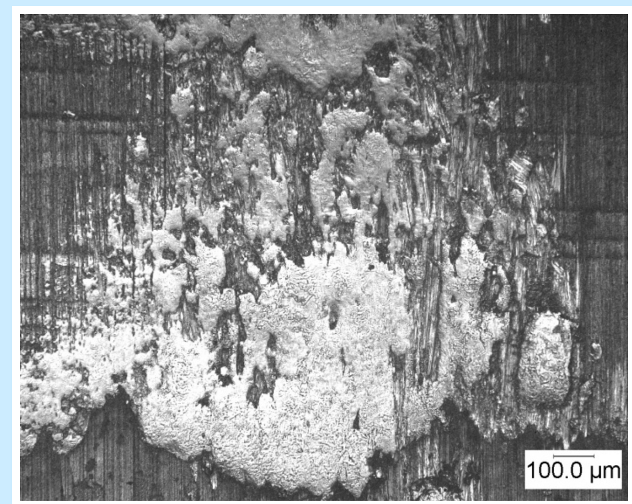
Technical Accomplishments (5/5)



- High-temperature, repetitive impact tests of exhaust valves against Ni-alloys at 750° C indicate the important roles of plastic deformation and shear in valve seat recession.
- Repetitive deformation effects will be incorporated into a new wear model.



Wear damage on the valve sealing surface



Wear damage on the opposing block surface

Future Work

- **Model development** (May - September 2009): Experimental work will be completed, and results will form the basis for a model for the progression of oxidation-assisted surface damage in diesel engine exhaust valve alloys.
- **Final report**: This project concludes in FY-09. The final report will summarize the following major findings and outputs of this work:
  - How Fe-, Ni-, and Co-based alloys change their oxidation behavior in the presence of mechanical contact damage at high temperatures.
  - Differences in oxidation/wear behavior under different forms of surface damage: sliding, abrasion, or repetitive impact with slip (as in valves/valve seats)
  - How the conjoint effects of wear, deformation, and oxidation can be modeled to aid in the selection of diesel engine exhaust valve materials.

Summary

- The compositions of the oxides that form during wear of high-performance alloys at elevated temperatures are different than if surfaces were oxidized without mechanical contact. Thus, one should not use static oxidation tests to predict durability of loaded surfaces in engines where tribological contact also occurs.
- Co- and Ni-based alloys had more uniform, less porous, less brittle scales than did the Fe-based alloy tested under the same conditions.
- Wear / oxidation effects at high temperatures vary depending on the *type* of wear that occurs (e.g., abrasive versus impact wear) because the mechanically-mixed layer and sub-surface defect structures affect both diffusion of reactants to the surface and the reaction kinetics once they arrive.
- In order of durability and oxidation resistance at high-temperatures, alloys studied ranked: Co-base, then Ni-base, then Fe-based. However, at lower mean operating exhaust temperatures, Ni- or Fe-based alloys may still be satisfactory.