Friction and Wear Reduction in Diesel Engine Valve Trains

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OAK RIDGE National Laboratory

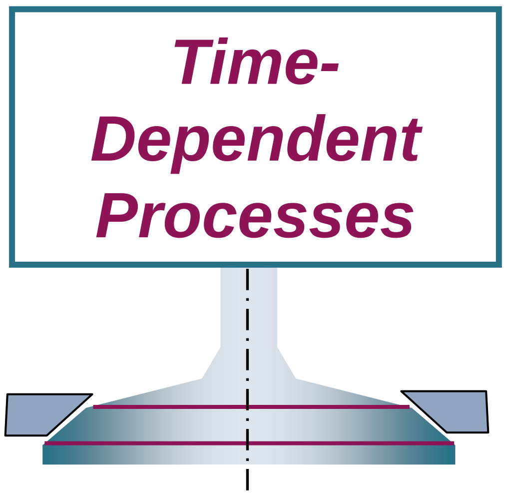
Purpose of the Work

- **Methodology**: To develop methods for characterizing the combined effects of mechanical damage and oxidation on the durability of exhaust valve materials at elevated temperatures.
- **Knowledge**: To improve our understanding of the science underlying high-temperature, oxidative wear processes in exhaust valve materials.
- **Application of knowledge**: To aid engine manufacturers in selecting and developing durable, long-lasting valve train materials for the next generation of fuel efficient, low-emissions diesel engines.

Barriers

- Valve and seat wear leads to loss of compression, loss of engine efficiency, repairs, and increased emissions. Hotter-running engines demand more of materials.
- A better understanding of the conjoint effects of mechanical contact, oxidation, and elevated temperature is needed to select durable valve and seat materials and surface treatments. This is a challenging, multi-disciplinary problem.

Understanding valve wear involves integrating mechanical, metallurgical, chemical, and time-dependent processes



- **Alignment between valve/seat**
- **Wear-in of the valve face**
- **Wear-in of the seat**
- **Progressive lateral displacement of material**
- **Thermal cycling during start-up/shut-down/idle**
- **Aging of the alloys**
- **Surface/ sub-surface oxidation in the presence of repetitive contact**
- **Mechanical mixing of surface material – effects of scales, debris, and transferred material on damage accumulation**
- **External material sources: ash and other deposits**

THIS WORK

Technical Approach

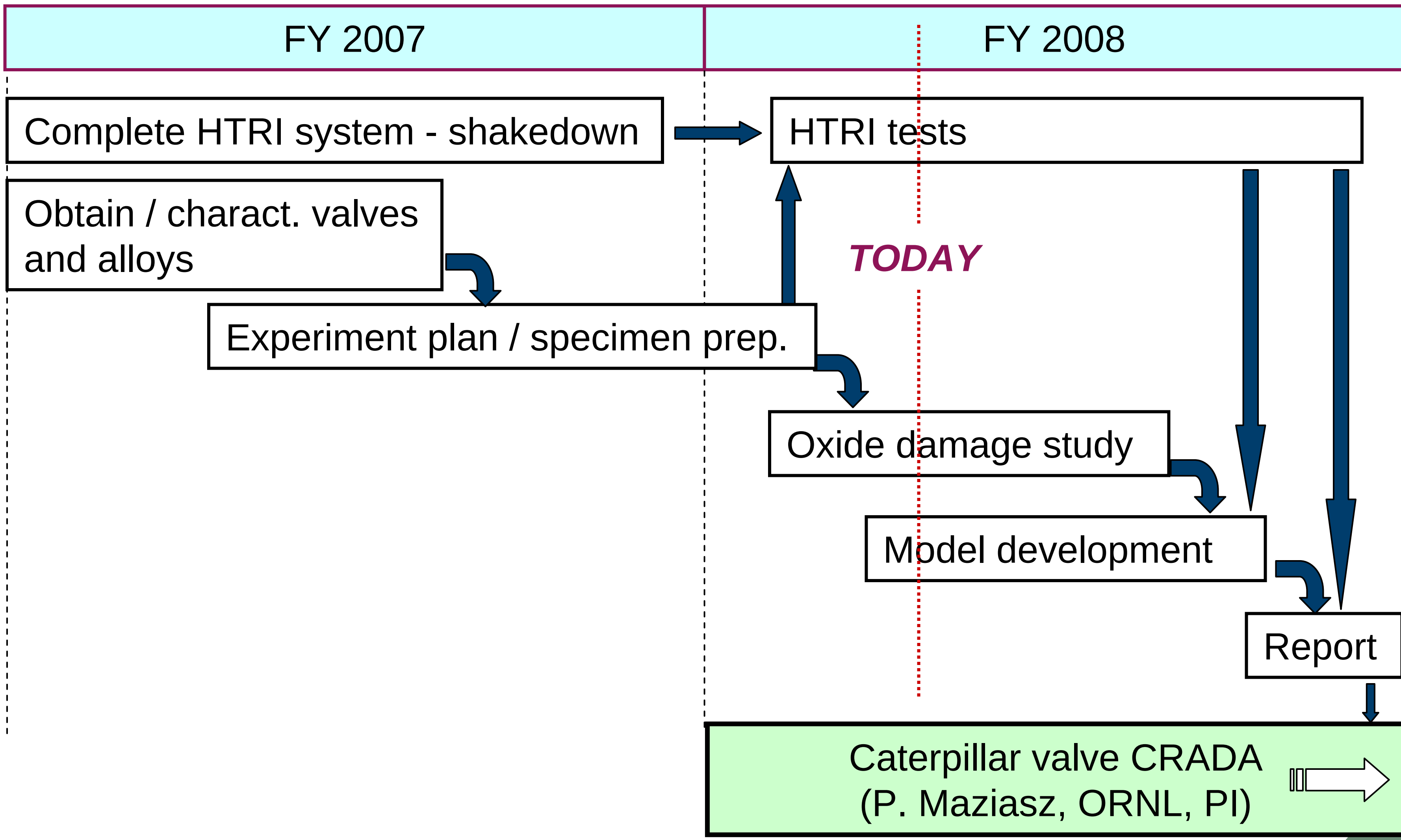
1) **Design and build a high-temperature repetitive impact apparatus** to wear-test both simple coupons and actual valves.

2) **Conduct experiments** to understand the role of mechanical surface damage on high-temperature oxidation and re-oxidation (healing) of superalloy surfaces.

3) **Develop a valve/seat recession model** to account for simultaneous wear and oxidation.

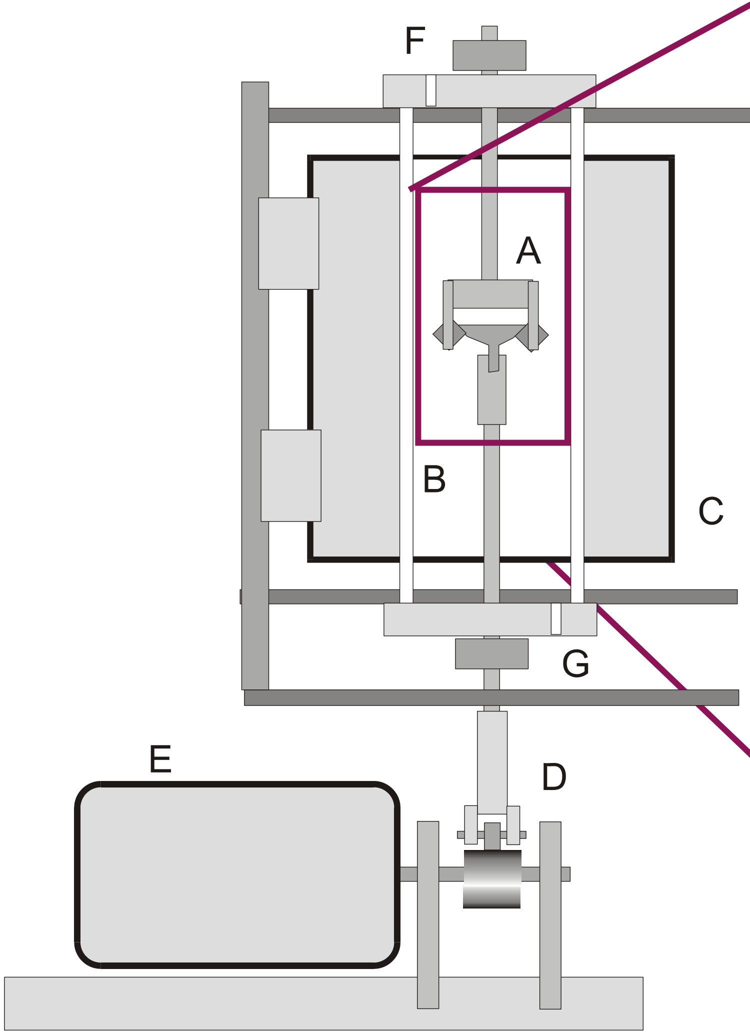
4) **Work closely with a diesel engine builder** to understand engine valve wear behavior, and to help us select our test conditions to produce relevant results for material selection.

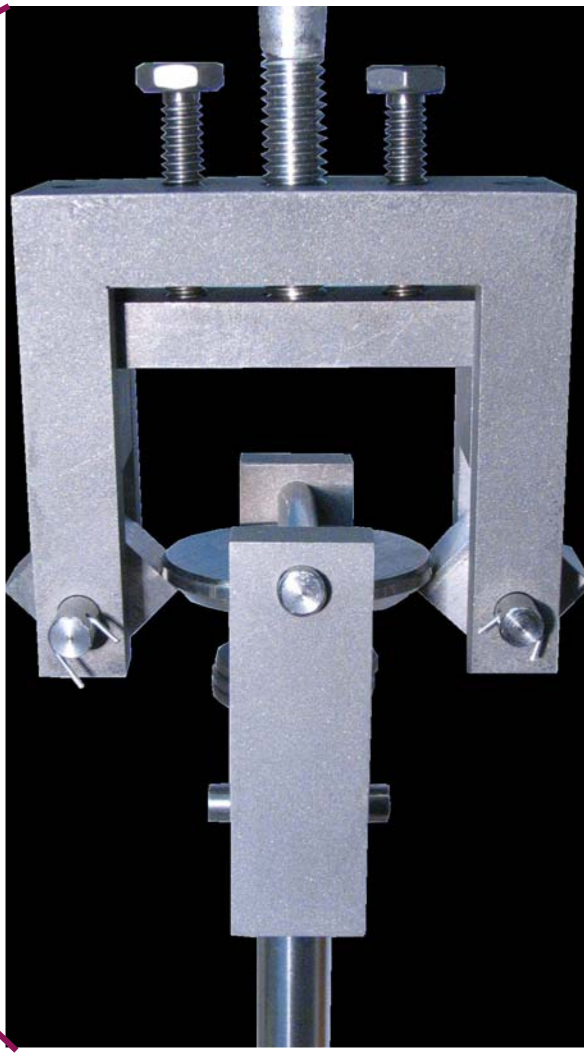
Research plan



(I) Design and Construction of a High-Temperature Repetitive Impact Testing System (HTRI)

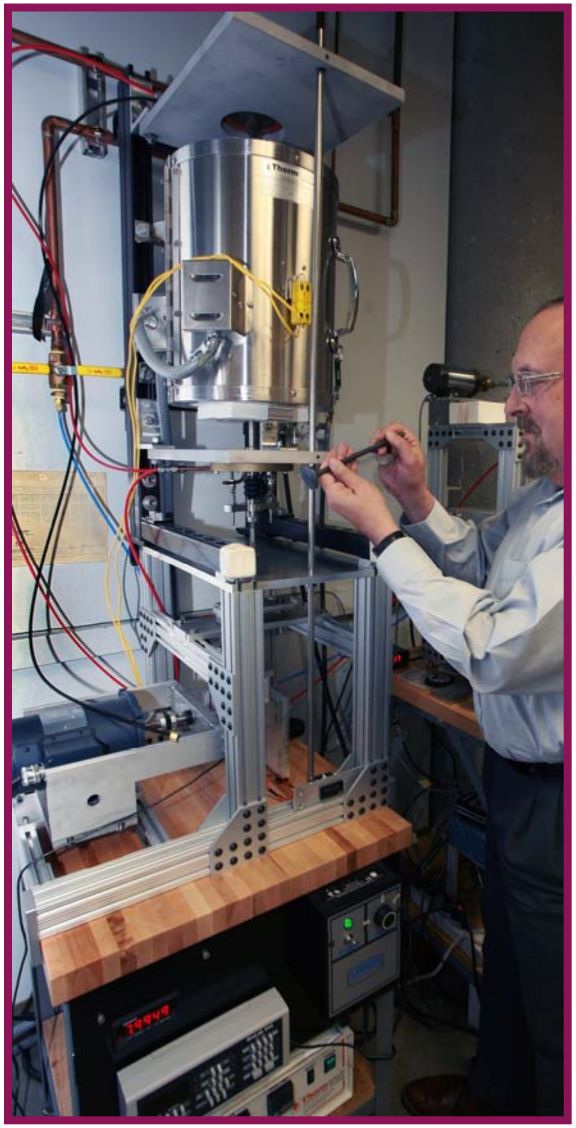
Features of the HTRI in the Valve Head Testing Configuration



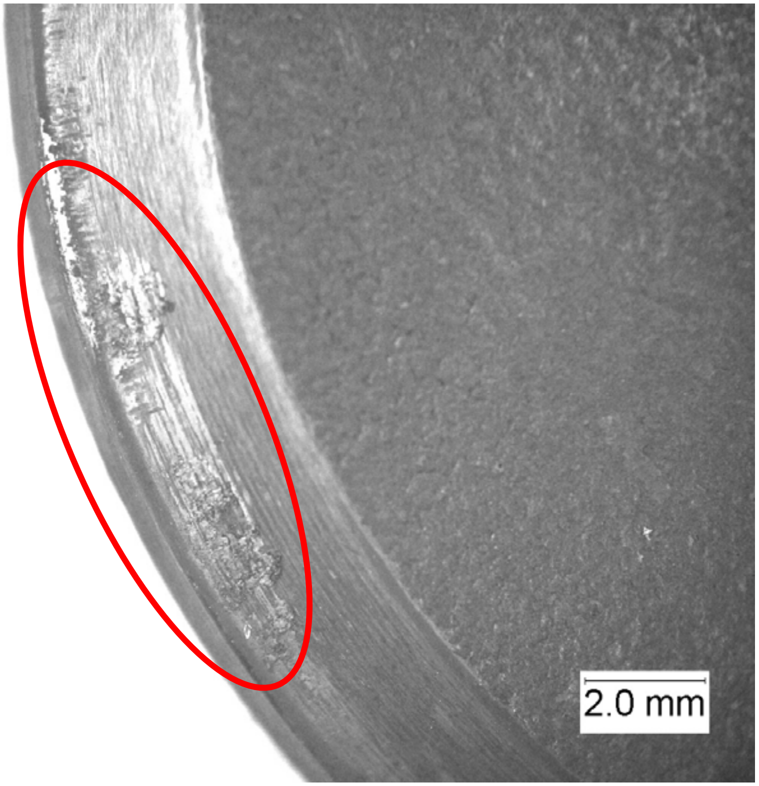


Exhaust valve

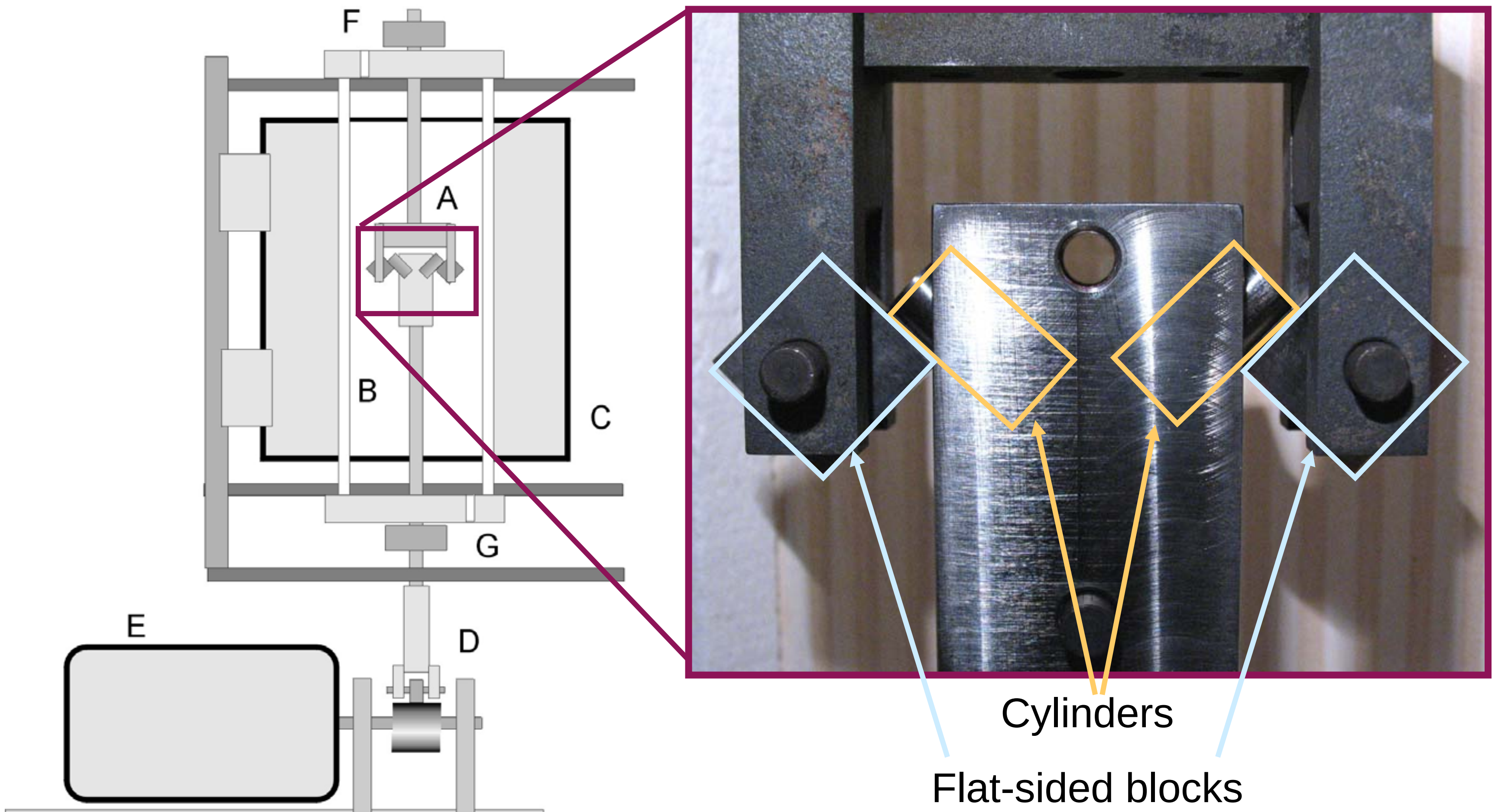
Initial experiments at 800º C on a Ni-based, commercial exhaust valve



- Surface damage from 20,000 impacts displays micro-welding, plastic deformation, and transfer.



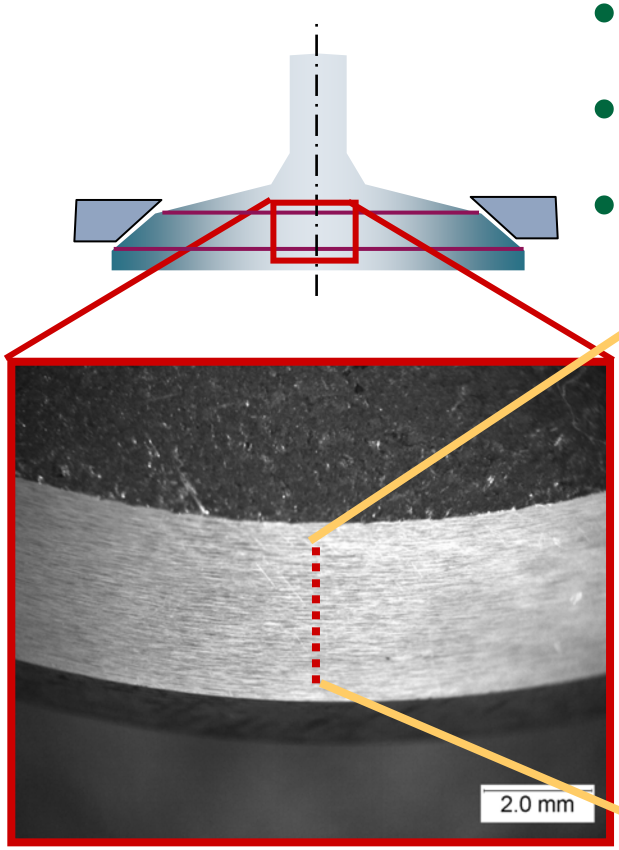
Features of the HTRI in the Simple Coupon Configuration

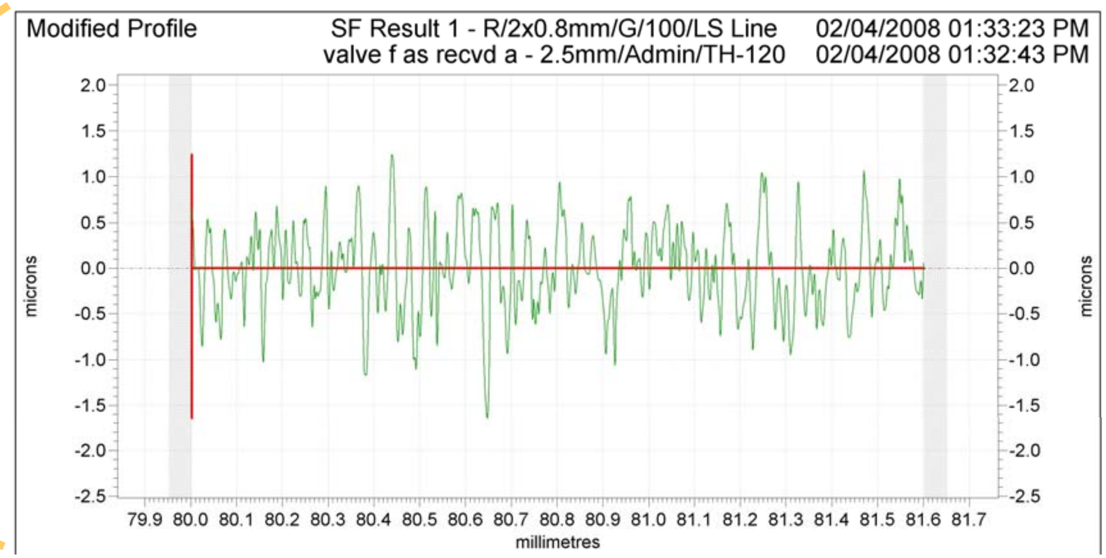


Inclined pin-on-flat (45 deg)

Test conditions – coupon tests

- **Match surface finishes (valve/ test coupons)**
- **Match temperatures (700 – 850º C)**
- **Combine oxidation with mechanical wear**





Production valve: Ra = 0.354 μm, Rz = 2.504 μm

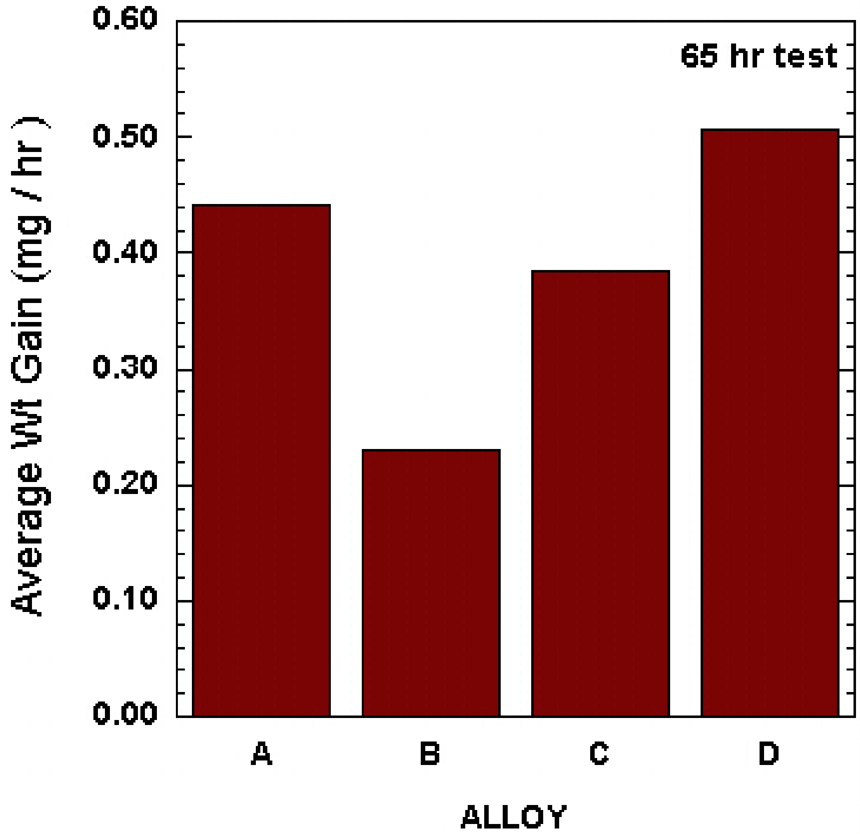
HTRI test coupon: Ra = 0.476 μm, Rz = 3.933 μm

(II) Experiments on Re-healing of Damaged Oxides on Valve Materials

- As the engine operates, oxides grow on the exhaust valve surfaces but are destroyed by wear.
- Do the oxides that re-form on worn surfaces have the same composition and properties as the oxides on undamaged surfaces?

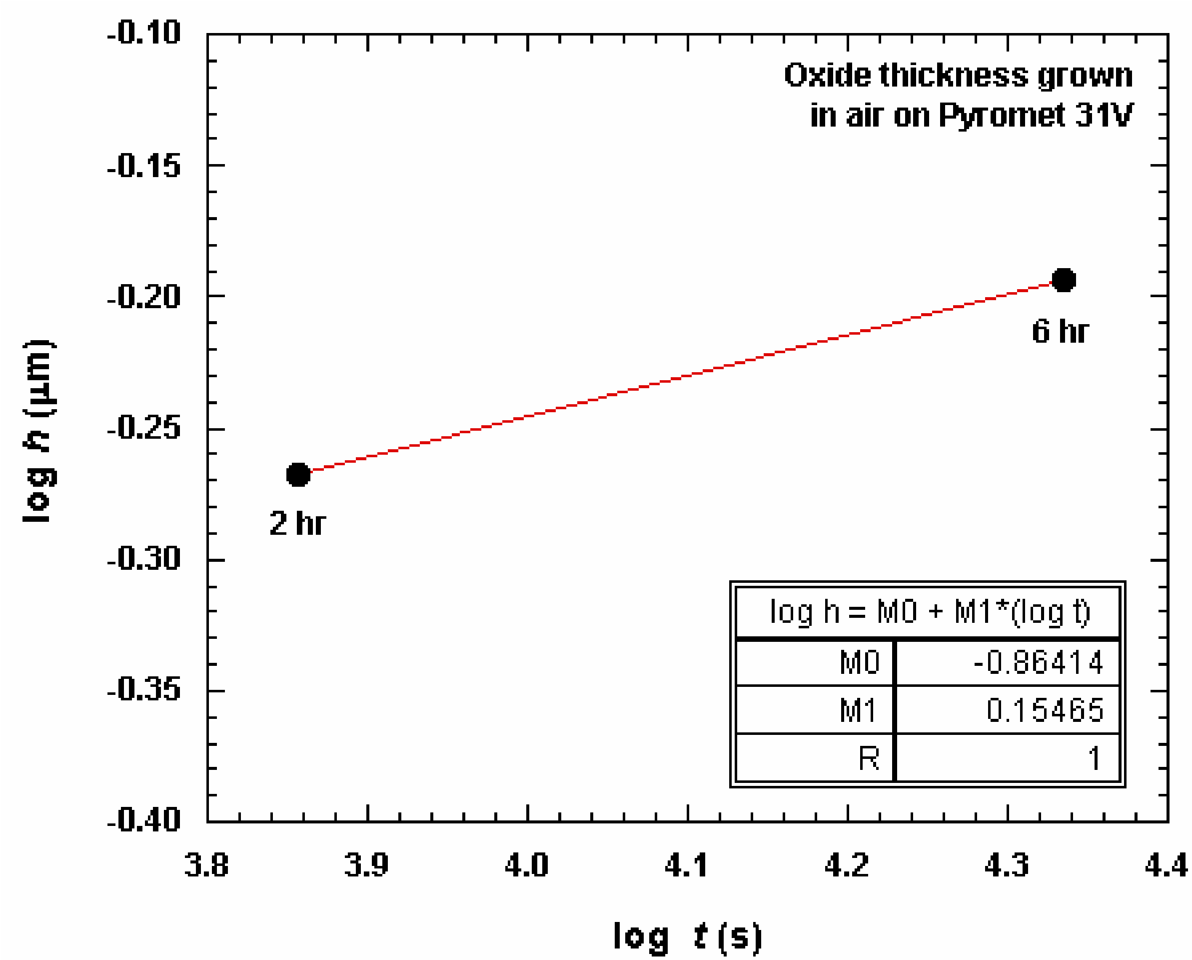
Alloy composition affects oxide scale formation at 870º C* (Ni-based alloys)

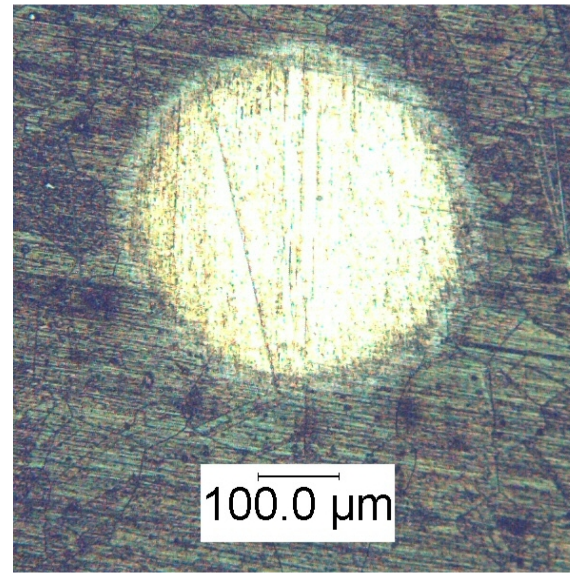
Wt%	Alloy A	Alloy B	Alloy C	Alloy D
Cr	29.	29.	29.	29.
C	2.4	2.2	2.0	2.2
Si	1.0	1.5	1.2	1.5
Mn	0.5	-	-	-
Co	10.0	-	-	-
W	15.0	14.0	-	-
Mo	-	-	8.5	8.5
Fe	8.0	8.0	8.0	25.



*Narasimhan, et al. (1981) *Wear*.

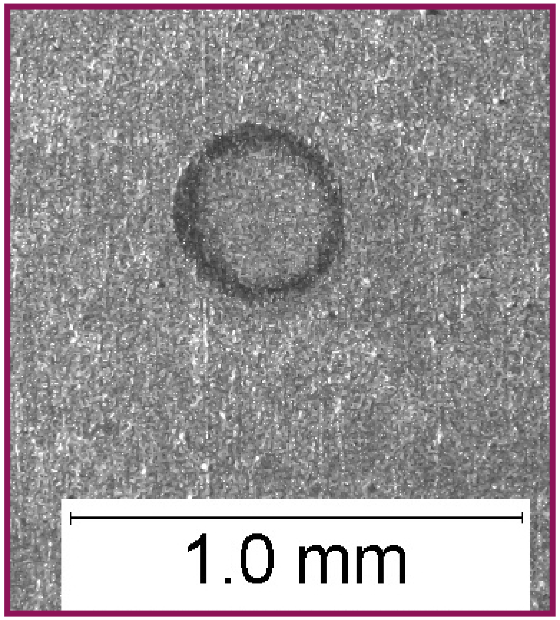
Logarithmic oxide growth rate for a Ni-Cr-Fe valve alloy in air at 850º C





A micro-abrasion technique was used to measure oxide thickness

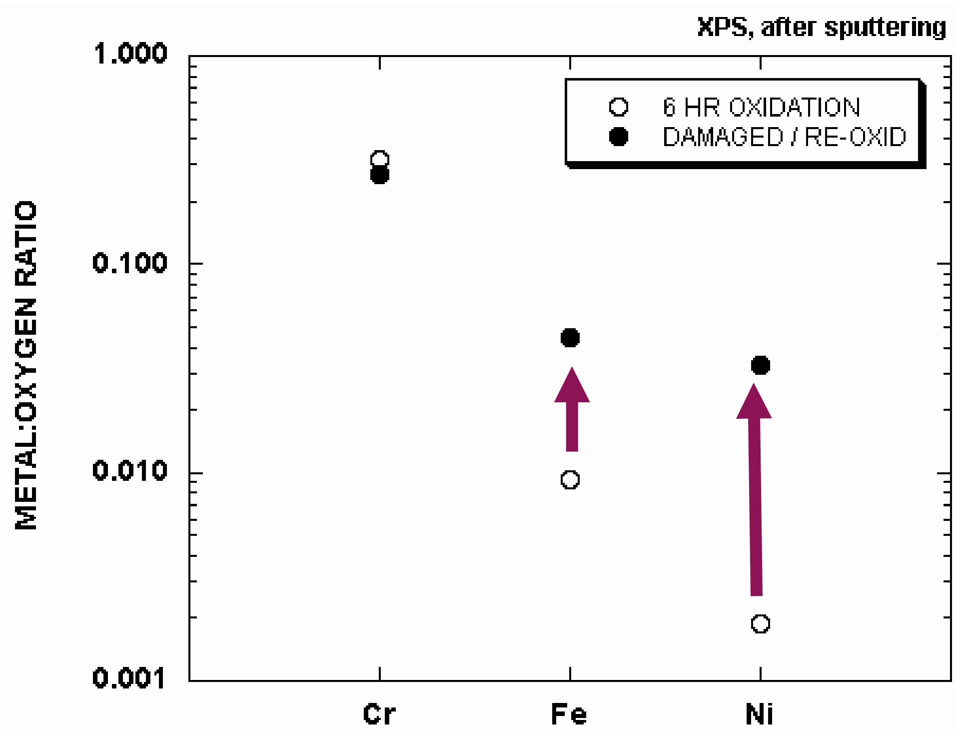
The oxide that re-grew on damaged areas of a valve alloy differed in composition



Oxidized 2 hrs at 850° C, exposed substrate by dimpling, then re-oxidized for 4 more hrs at 850° C

XPS data, H. Meyer, ORNL

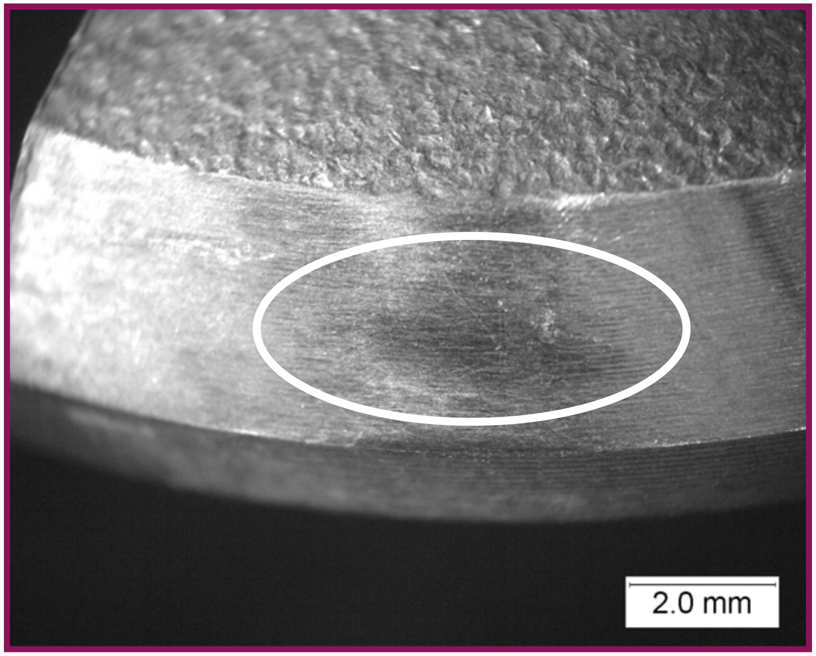
Alloy (wt%) 57 Ni, 22.7 Cr, 13.3 Fe + bal.



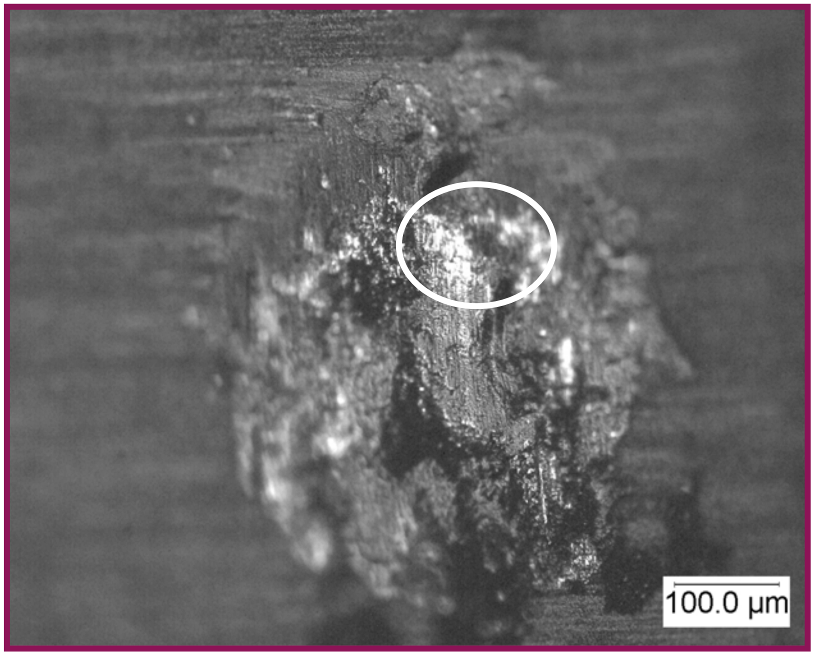
Fe, Ni enriched on damaged area

(III) HTRI tests will combine impact and slip at temperatures ranging from 700 - 850º C

Combinations of high temperature exposure and mechanical damage will be applied to the surface.



Abrasion of the scales affects the oxide that reforms

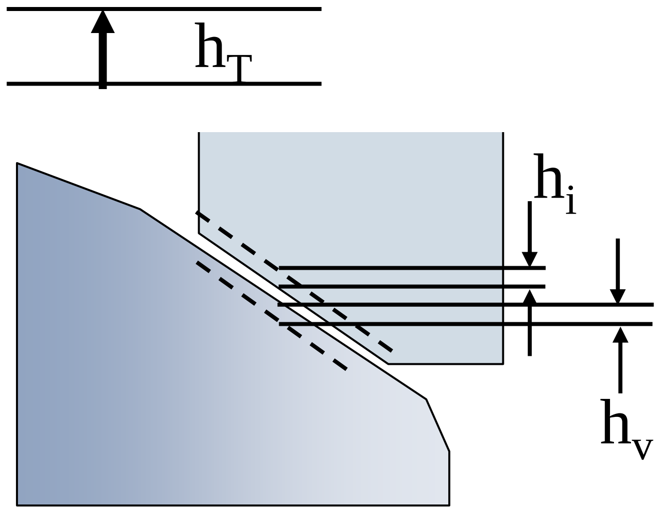


1000 repetitive impacts mixes oxide into the substrate alloy

Three 'model' alloys based on Fe, Ni, and Co have been selected for HTRI testing

Element	Stellite 6B*	Pyromet 80A**	Custom 465**
Fe	2.65	0.75	bal. (~74.)
Ni	2.48	bal. (~ 74.)	10.75 – 11.25
Co	bal. (~ 58)	1.00	-
Cr	29.8	20.00	11.00 – 12.50
Mn	1.46	0.35	0.25 (max.)
Mo	0.06	-	0.75 – 1.25
Si	0.55	0.35	0.25 (max.)
Ti	-	2.35	1.50 – 1.80
Cu	-		-
Al	-		-
W	3.78	-	-
C	1.02	0.06	0.02 (max..)
S	< 0.01	0.007	0.010 (max.)
P	< 0.01	-	0.015 (max.)
Comments	Co-based, superalloy used for corrosion- and wear-resistance 0.05 1.25	Ni-based, oxidation resistant alloy with creep-resisting properties	martensitic Fe-base, age-hardenable alloy designed for corrosion resistance
HV, GPa (200 gr)	7.75	2.80	5.75

(IV) A Valve Wear Model is Being Developed



Total recession, h_T

$$h_T = h_i + h_v$$

For each side (valve and seat):

$$h_i = (d_i + w_i) - (y_o + t_i)$$

d = plastic deformation

w = wear loss

DISPLACEMENT AND LOSS

y_o = oxide growth

t = material transfer

MATERIAL GAIN

Performance Measures and Accomplishments

- Designed, built, and tested a high-temperature repetitive impact testing apparatus (HTRI)
- Began a two-pronged experimental plan: (a) HTRI tests and (b) damage studies on pre-oxidized surfaces
- Established initial framework for a wear-oxidation model
- Coordinated work with Caterpillar

Technology Transfer

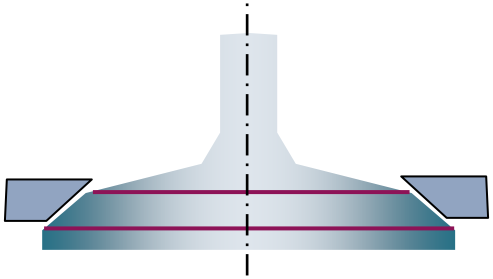
- Coordinated work with Caterpillar on a periodic basis, including use of commercial exhaust valves / seats provided by Caterpillar as part of the test matrix
- Participation in project reviews like this one
- Final report due September 2008

Publications / Patents

- Paper on wear-oxidation mechanisms of high-temperature alloys is planned for the “International Conference on Wear of Materials”
- Patents: (none)

Plans for Next Fiscal Year

- This project is scheduled to end in FY 2008.
- The final report and publications will suggest directions for further work.



Summary: Friction and Wear Reduction in Diesel Engine Valve Trains

- Complex wear-oxidation processes affect the durability of diesel engine exhaust valve contact surfaces.
- A new HTRI was designed and built to investigate these processes.
- Experiments will support the development of a materials-based valve/seat surface recession model.
- The fundamental knowledge gained here will complement the R&D efforts of engine designers.

- *Added benefit* :   The HTRI will become available to industry and university researchers through the Tribology Research User Center in the High Temperature Materials Laboratory User Program.

Many thanks to …

- DOE/EERE/OFCVT – Jerry Gibbs
- ORNL:
  – Ray Johnson, Brian Jolly, Harry Meyer, Phil Maziasz, Neal Evans, Jun Qu, Ian Wright, Jerry McLaughlin,
- Caterpillar:
  – Nate Phillips, Jeff Jensen, Eric Kelsey, Jeremy Trethaway (fmr CAT), John Truhan