Materials for HCCI Engines

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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Overview

Timeline

- Project start: March 2005
- Project end: September 2010
- Percent complete: 90%

Budget

- Total project funding Received
  - DOE 100%
- Funding Received in FY09: $225k
- Funding for FY10: $225k

Barriers

Barriers Addressed

- Increasing engine efficiency while reducing pollutant formation
- Lack of availability of materials that meet projected operational performance parameters without exceeding cost constraints

Targets

- Improve passenger vehicle fuel economy 25%–40%
- Improve commercial vehicle engine efficiency at least 20%

Partners

- Lead: ORNL

Collaborators/Interactions

- Eaton – Manufacturer of valves
- Carpenter Technologies- Materials Supplier

Relevance and Objectives

- Technologies that increase engine combustion efficiency such as lean-burn operation (High Efficiency Clean Combustion), turbocharging, high levels of exhaust gas recirculation, variable valve actuation and/or variable compression ratios are required to reach engine efficiency goals while reducing pollutant formation
- Need to develop materials that meet projected operational performance parameters without exceeding cost constraints
- **Develop cost-effective exhaust valve materials suitable for operating at higher temperatures (870°C vs. current 760°C) for use in advanced engine concepts**
  - Test current exhaust valve material for fatigue performance at higher temperatures and compare performance with other suitable candidate materials
  - Identify materials (if any) or develop new materials with high temperature stability and fatigue properties appropriate for operation at the higher temperatures based on fatigue data obtained earlier

Milestones

FY 2009

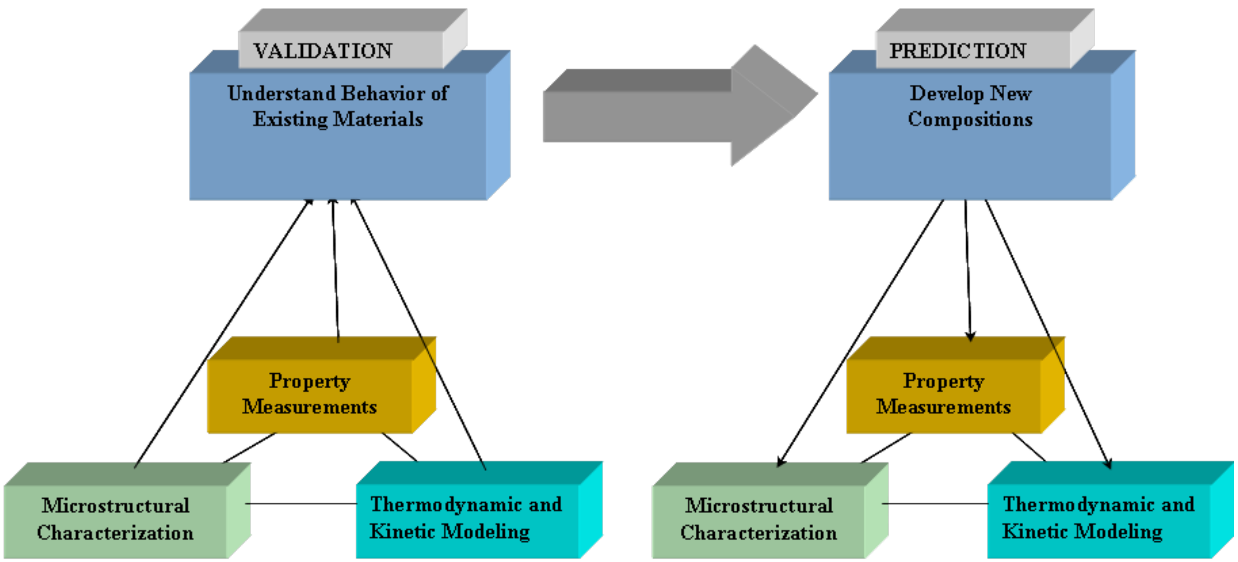
- Develop material with appropriate performance/cost ratio for use in automotive exhaust vales in advanced engines using computational design approach (9/09)

FY 2010

- Complete selection of one commercial alloy and one newly developed alloy for high temperature valve application (9/10)

Approach

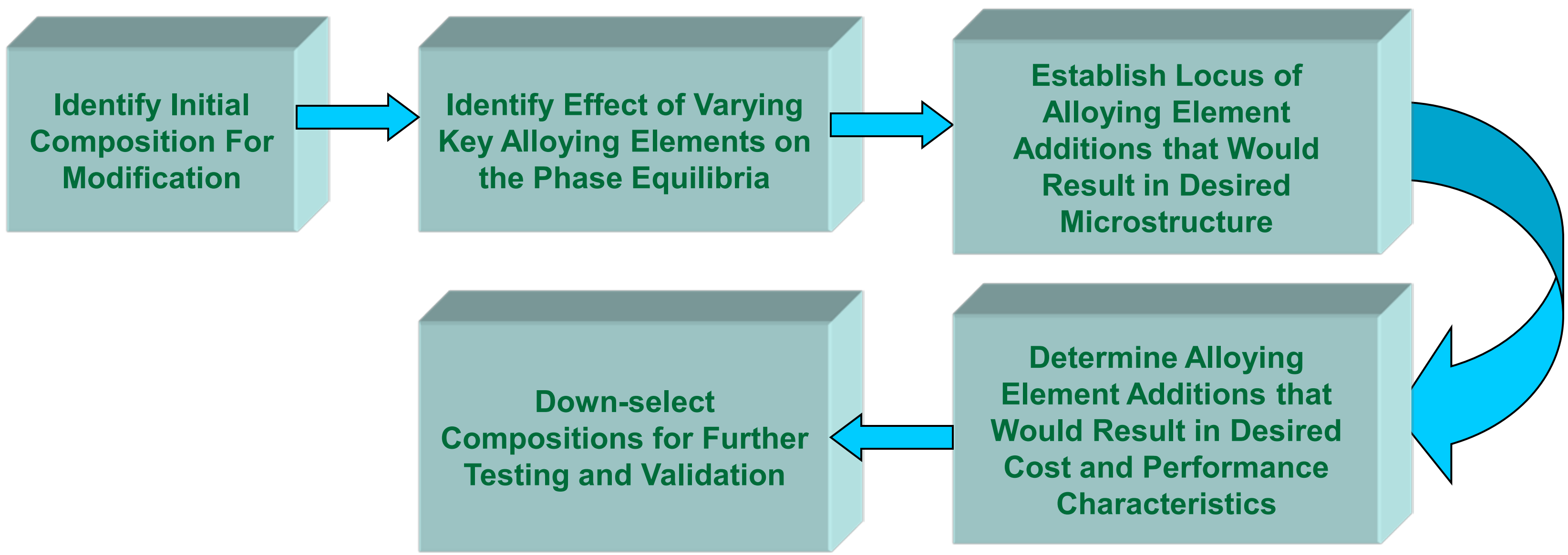
- Identify key material properties of interest for critical components
- Establish correlation between properties of interest and microstructural characteristics using existing alloys and identify desired microstructures
- Search composition space for alloys with desired microstructure and alloying element additions using validated computational models
- Reduce development time by selective testing of promising alloys with desired microstructure and cost



Why are New Alloys Necessary?

- **New alloys are required to**
  - Achieve improved performance when compared to existing alloys at same or reduced cost
  - Achieve desired performance while reducing expensive alloying element additions
  - Achieve manufacturability at low cost
- **Alloys have been developed by emulating microstructure of existing desirable alloys**

Example Methodology For New Alloy Development



Computational thermodynamic/kinetic modeling allows for rapid identification of new alloys with desired microstructure, and alloying element characteristics

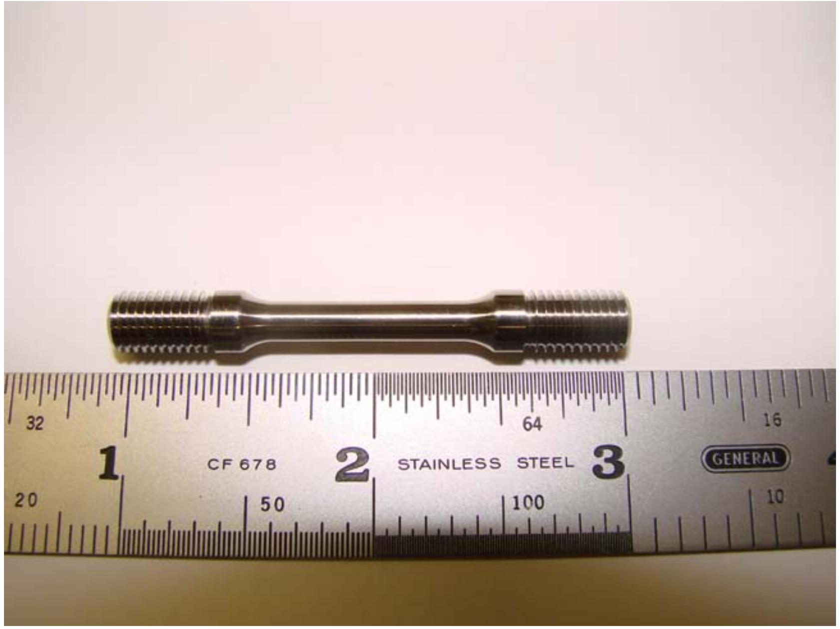
Technical Accomplishments and Progress: New Alloys with Potential to Perform at Higher Temperatures Have Been Developed

- Thermodynamic and kinetic modeling has been performed to correlate compositions with microstructure in selected commercial alloys
- Microstructural characterization has been carried out to verify specific computational predictions of microstructure
- High temperature fatigue properties using fully reversed fatigue tests have been obtained from alloys with well-defined compositions, heat-treatments, and microstructure
  - Relationship between rotating beam fatigue data (required by the industry) and fully reversed fatigue data has been developed
  - Desirable microstructures have been identified
- Several commercial alloys with the desired microstructure have been identified and performance has been verified using rotating beam fatigue tests
- Several new alloys with lower alloying Ni and Co contents with microstructures comparable to commercial alloys have been developed
  - Initial tensile tests show that new alloys have good high temperature strength

Technical Accomplishments: FY 09

- Computational modeling was carried out along several composition schemes to identify new alloy compositions with comparable/better properties with cost benefits
- Several alloy compositions with desirable microstructures and lower amount of expensive alloying elements (Nickel, Cobalt) have been identified with the potential for improved performance/cost ratio
- Selected alloys have been prepared in small quantities, tensile tests have been completed at room temperature and 870^{o}C, and microstructures have been studied
- Best alloy composition has been chosen and larger heat has been prepared to enable fatigue testing

Small Heats Were Prepared, Rolled, and Tensile Specimens Have Been Machined and Tested



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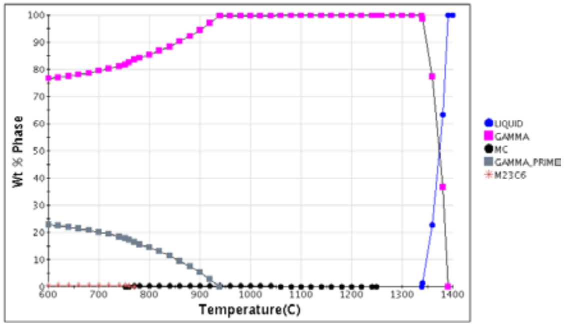
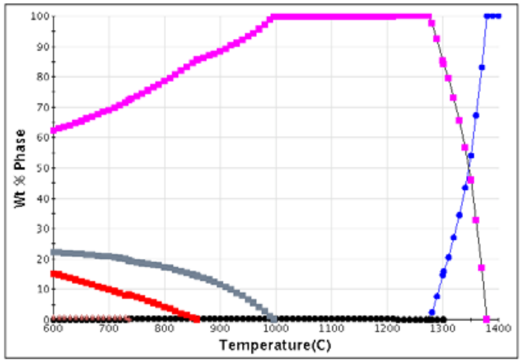
New Alloys Have Hardness Values Comparable to Desirable Commercial Alloys in Aged Condition

X751



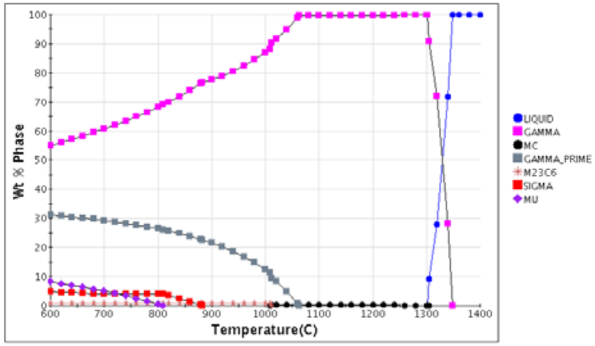
Vickers Hardness= 301

New Alloy



Vickers Hardness = 407
HCCI-4

Udimet 520

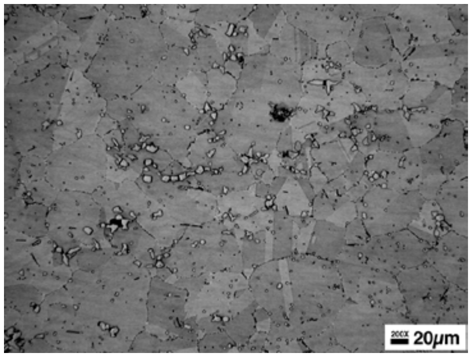


Vickers Hardness = 420

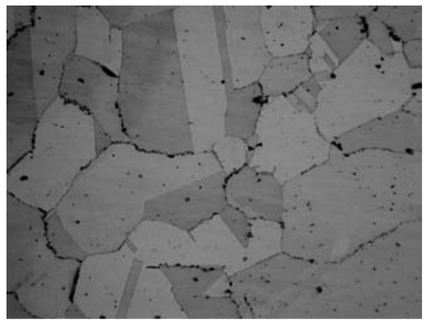
Desirable Commercial Alloy

New alloys have a significantly lower Ni content and hence lower cost

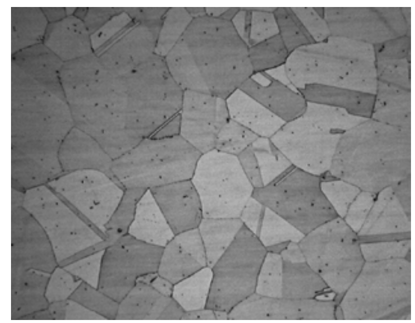
Alloys Tested Have a Wide Range of Strength at 870^{o}C in the Aged Condition



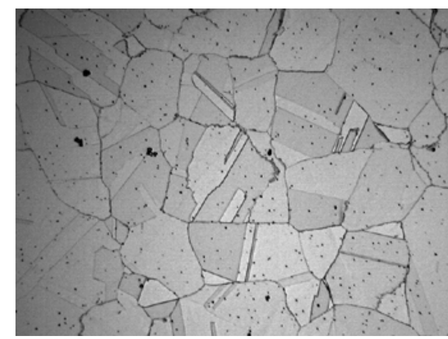
HCCI-2
0.2% YS= 46.5 Ksi



HCCI-4
0.2% YS= 65.5 Ksi



HCCI-9
0.2% YS= 63.4 Ksi

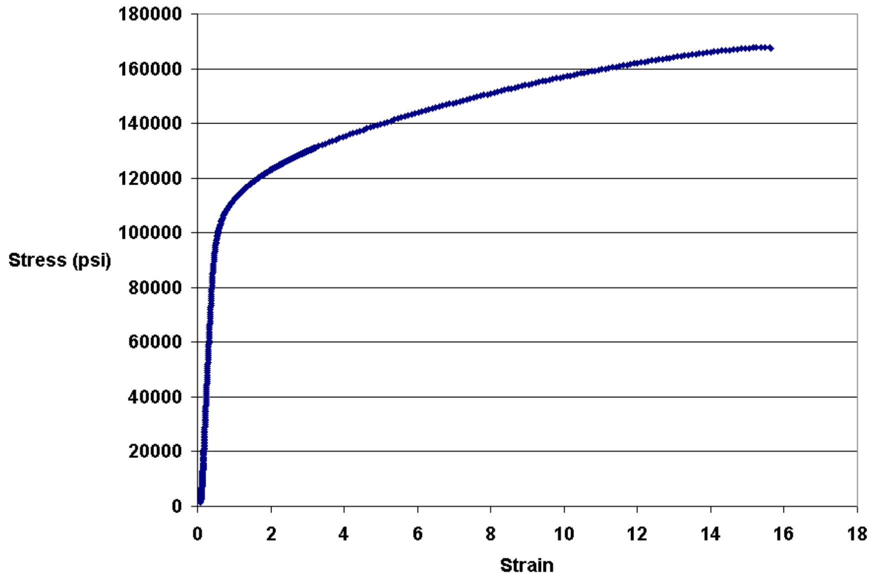


HCCI-16
0.2% YS= 71.5 Ksi

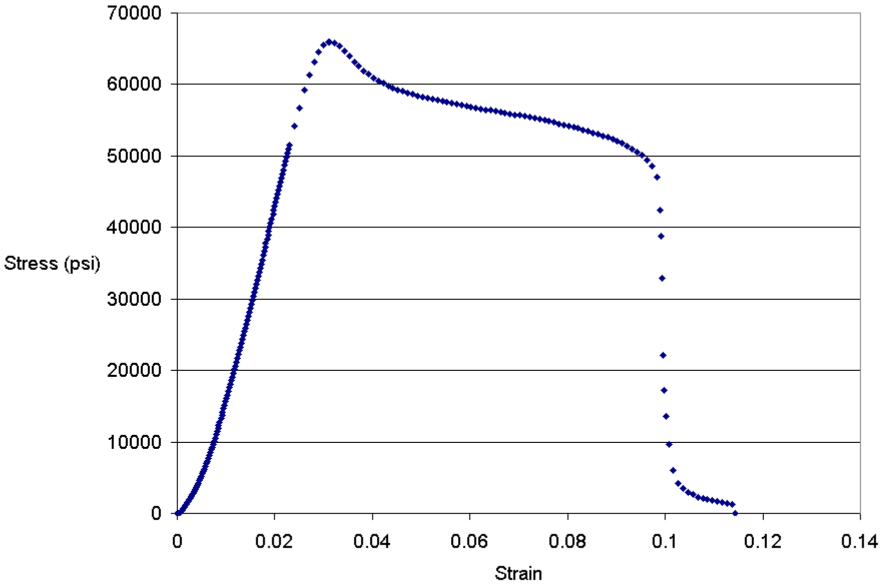
Comparable commercial Ni-based alloys YS at 870^{o}C= 40-80Ksi

(Reference: L. M. Pike, Superalloys 2008, pp.191-200)

One Promising Alloy With Desirable Strength and Ductility in Aged Condition Has Been Selected



RT, 0.2% YS= 104.8 Ksi

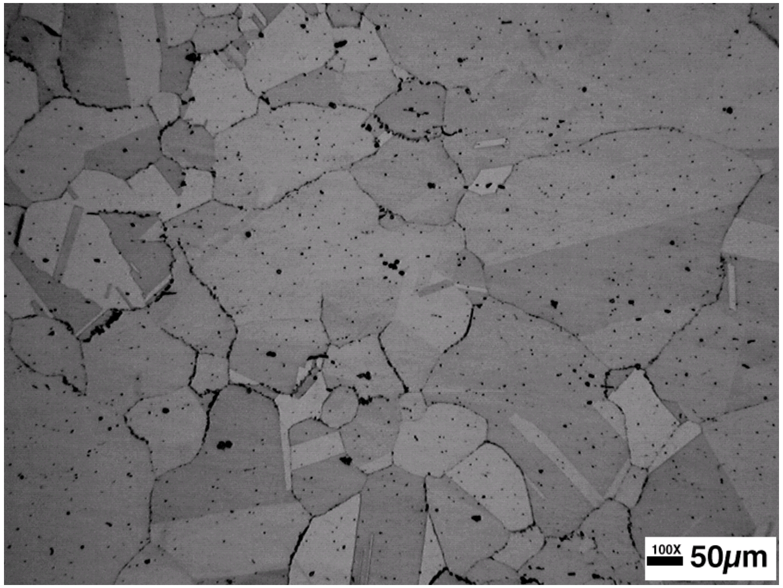


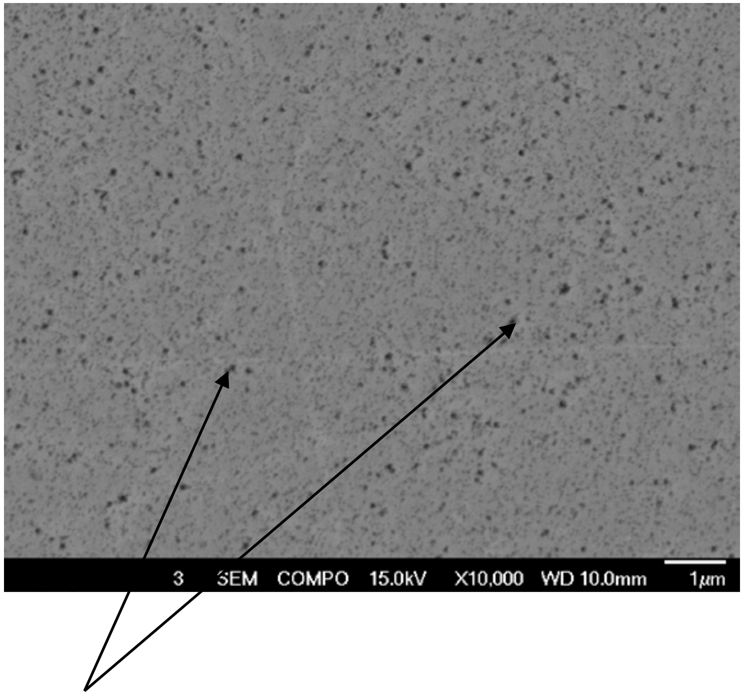
870^{o}C, 0.2% YS= 65.5Ksi

New alloy has a much lower Ni +Co content (less than 50 wt.%) Vs. Commercial Alloys (greater than 60 wt.%)

Alloy can be easily processed using standard techniques

Microstructural Evaluation of the Promising New Alloy Reveals Desirable Fine Precipitation





Small Strengthening Precipitates

A Larger Heat Has Been Prepared of the Selected Alloy and Thermo-mechanically Processed for Fatigue Testing

Collaborations and Coordination with Other Institutions

- Extensive discussions including guidance for future work are on-going with Eaton Corporation
- Discussions have also been carried out with Carpenter Technologies
- Follow-on cost-shared commercialization plan for valve applications has been proposed with Eaton Corporation

Future Work

FY10

- Evaluate effect of long term exposure at 870^{o}C on alloy tensile properties
- Complete rotating beam fatigue and fully reversed fatigue tests on the best new alloy
- Optimize alloy composition development to seek further improvements in alloy properties (if required)
- Complete microstructural characterization of newly developed alloy/s
- Disclose composition of new alloys for one/more patent applications

Summary

- Improvement in high temperature capability of exhaust valve materials is an enabler for future advanced engine concepts with higher efficiencies
- Targets for improvement are the fatigue properties at 870^{o}C and performance/cost ratio of exhaust valve materials
- Several commercial alloys with potential for improved performance at the higher temperature have been identified based on microstructural characteristics and performances have been verified using rotating beam tests
- New alloys with good high temperature strength and improved performance/cost ratio have been developed using computational modeling techniques