Ultra-Fast Chemical Conversion Surfaces

Ali Erdemir (PI)
Osman Eryilmaz (Co-PI), Vivekanand Sista(Co-PI)
Argonne National Laboratory
April 07, 2010

Project ID # PM027

Overview

Timeline

- Start: 10/01/2009
- Finish: 9/30/2014
- %15 Complete

Budget

- Total project funding:
  - DOE Share: $1M
  - Contractor Share: $250K
- Funding Received in FY09
  - (none, new project)
- Funding received in FY10
  - $200K

Barriers

- Ultra fast chemical conversion of steel surfaces into very hard and thick boride layers in a very short processing time without distortion and cracks.
- Applications to intricate (odd-shaped) engine parts with excellent uniformity.

Targets

- Drastically increase wear resistance and durability of materials for use in various engine parts and components.
- Develop and scale-up the process and demonstrate superior friction and wear performance under severe operating conditions.
- Verify cost competitiveness and transfer demonstrated technology to industry for use in automotive and heavy vehicle propulsion systems.

Partners

- Bodycote Thermal Processing, Inc.
- Lead: Argonne National Laboratory

Objectives

- Develop and optimize ultra-fast boriding process for achieving much higher durability and efficiency in sliding, rolling, and rotating engine components including, gears, bearings, piston pins and rings, fuel injector components, tappets that require higher wear resistance and lower friction especially under severe operating conditions.
- Compare results with carburized and nitrided surfaces and elucidate friction and wear mechanisms.
- Demonstrate technical feasibility and superior property, performance, and durability characteristics of treated parts.
- Demonstrate scalability, cost-competitiveness, commercial viability.

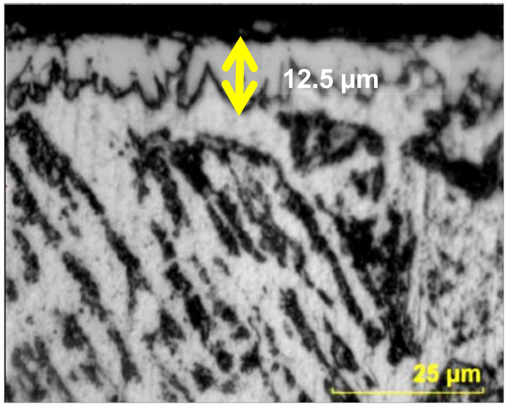
Milestones or Go/No-Go Decisions

- **FY10:**
  - **Milestone:** Demonstrate ultra-fast boriding of large numbers of test samples made out of the same steels as those used in the manufacturing of engine components.
  - **Milestone:** Complete testing and comparison of the mechanical and tribological properties of ultra-fast borided surfaces with those of the carburized and nitrided surfaces.

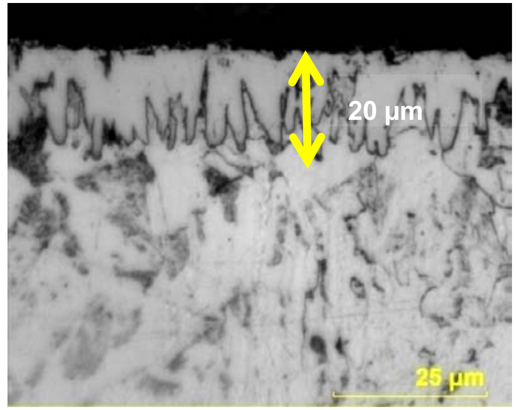
Approach

- Optimize process variables and develop reliable boriding protocols that can consistently result in ultra-hard and uniformly thick boride layers on test samples (nearly complete).
- Perform comprehensive lab-scale studies to confirm superior performance and durability of borided surfaces compared to nitrided and carburized surfaces (underway, initial results are very impressive).
- Determine effects of boride layer thickness, hardness, and chemical state on friction, wear, and scuffing performance (in progress).
- Employ optimized boriding protocols to appropriate engine parts, like piston pins, rings, tappets, etc. and confirm their superior mechanical and tribological properties (future plan).
- Demonstrate scalability and cost-competitiveness, transfer optimized technology to industry (Future plan).

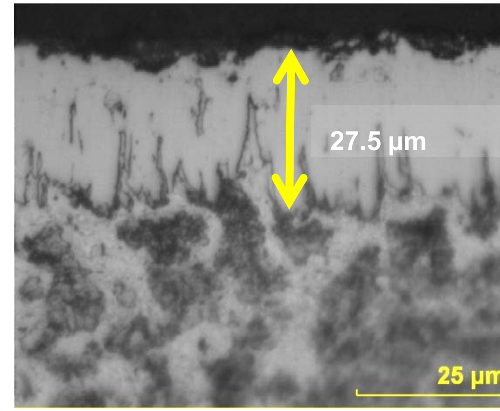
Technical Accomplishments/Progress/Results
(Optimization of Process Variables-Effect of Current Density)



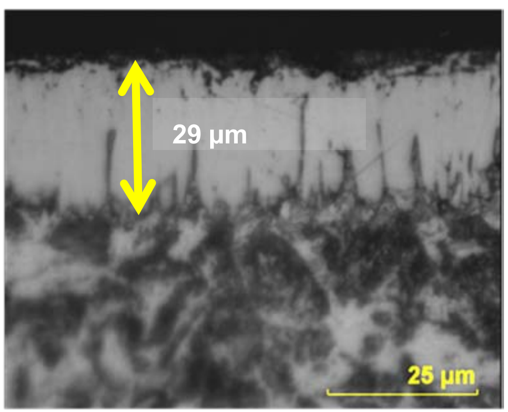
50 mA/cm^2



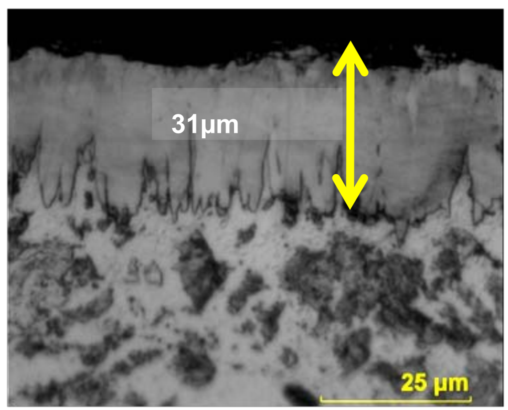
100 mA/cm^2



150 mA/cm^2



200 mA/cm^2



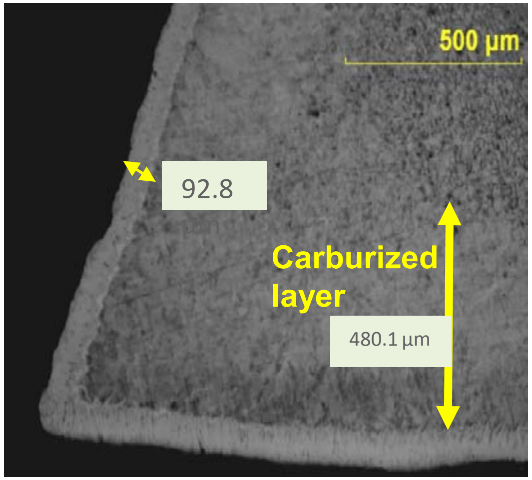
300 mA/cm^2

[10% Na_2CO_3 + 90% $Na_2B_4O_7$, **5 minutes**, 950° C]

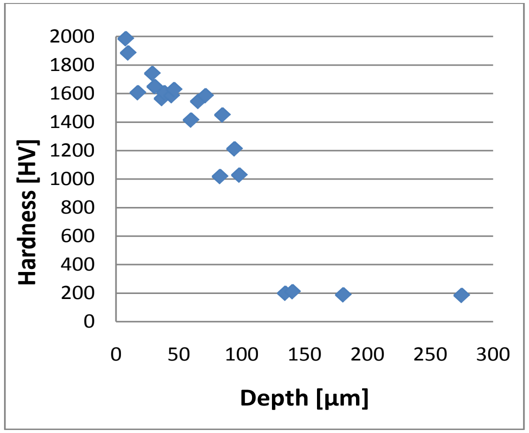
- **Test Conditions:**
  - Test Material: Steel (AISI1018)
  - Boriding Duration: <u>5 minutes</u>
  - Current density: Variable
- **Major Findings:**
  - Our method is truly ultra fast (more than 30 µm thick boride layer in 5 min).
  - Thickness increases rapidly with current density.
  - Denser morphology at higher current densities.

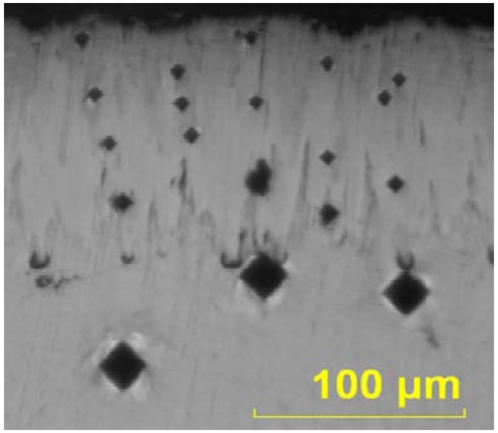
Technical Accomplishments/Progress/Results
(Boriding of Various Steels with Complex Shapes, Mechanical Properties)

- Accomplished boriding of plain and carburized steel with a complex geometry.
  - 1 hour of processing time results in a ≈90μm thick boride layer.
  - Very homogenous boride layer was produced on top of the carburized layer (≈480 μm thick)
- Hardness of boride layer is in the range of 1600 to 2000 Vickers (more than twice as hard of carburized/nitrided surface).



Boriding Conditions: 1 hour, 950C, at 200 mA/cm^2

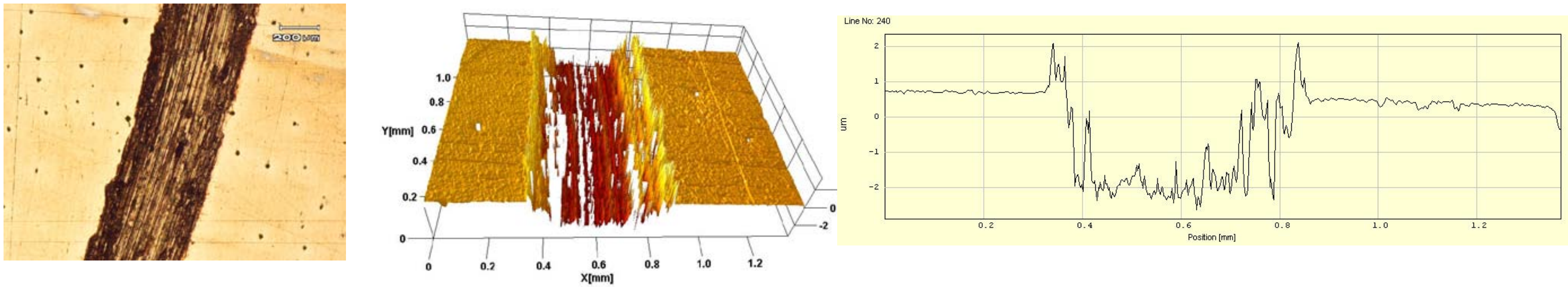




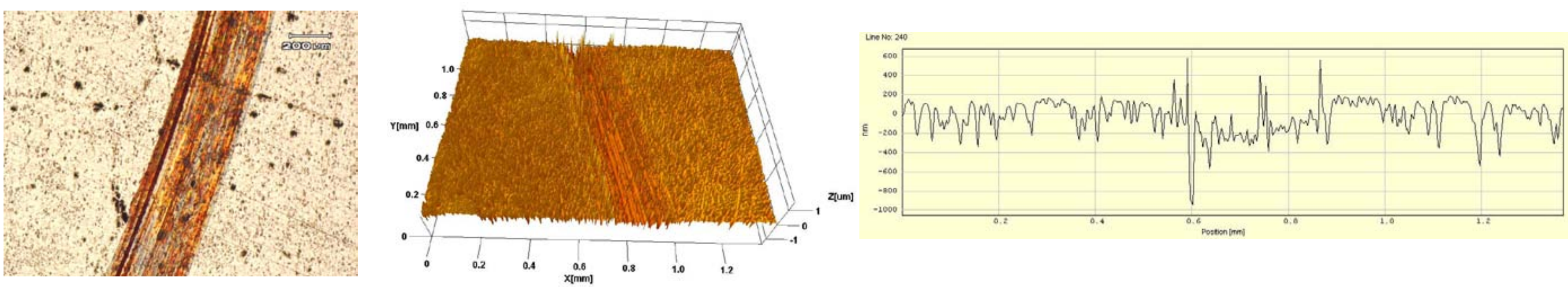
Technical Accomplishments/Progress/Results

Preliminary Tribological Characterization

Test Conditions: 5N Load, 6.3 cm/s, 1 hour, room temperature)



Wear damage on control (un-treated) steel)

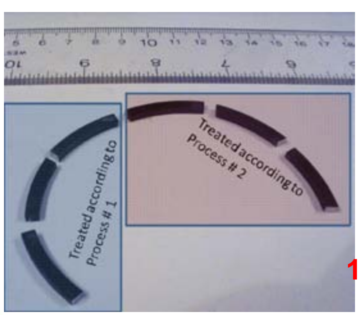


Wear damage on borided steel

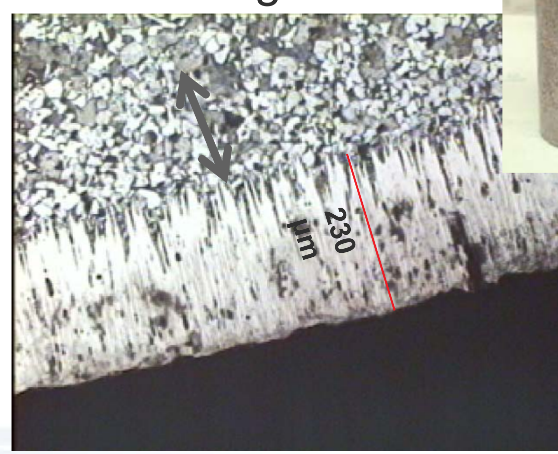
- Severe wear damage occurred on un-treated base steel, but there was very little wear on the borided steel.

Collaboration and Coordination with Other Institutions

- Bodycote North America: They are our primary industrial partner and have been providing strong help and guidance on industrial applications, optimization, scale-up and commercialization issues.
  - They are one of the largest heat-treatment and surface engineering company in US and serves many of the automotive OEMs and part suppliers with their carburizing, nitriding and coating processes.
  - They will be our technology transfer partner.
- Burgess-Norton: Processed successfully large number of piston pins
- Mahle: Tried our boriding process very successfully on their piston rings
- NASA: Processed NiTi alloys for high-performance bearing applications



160 µm thick boride layer after 1 hour boriding



Proposed Future Work

- **For the Reminder of FY10:**
  – Complete boriding of large numbers of test samples made out of the same steels as those used in the manufacturing of engine components.
  – Complete mechanical and tribological characterization studies.
  – Complete comparative studies with those of the carburized and nitrided surfaces (through close collaboration with Bodycote).
  – Verify process optimization and product quality, and establish model relationships between process conditions and product quality.
  – Develop reliable boriding protocols.
  – Initiate boriding of actual engine components.
- **FY2011:**
  – Further optimize and scale-up the boriding technique so that larger number of test samples and/or parts can be processed effectively and reliably (collaboration with Bodycote, Mahle).
  – Demonstrate reproducibility/reliability of the ultra-fast boriding process one batch after another.
  – Initiate component-level testing of representative engine parts and components.

Summary

- **Relevance:**
  - Ultra-fast production of very thick and hard boride layers on engine parts and components is expected to have a huge positive impact on the durability and performance of these parts and provide significant competitive edge for US heat-treating and auto industries.
- **Technical Approach and Accomplishments:**
  - Despite being a new project, we have made significant progress in meeting our stated goals and milestones by:
    - Setting-up chemical boriding and relevant test facilities
    - Demonstrating that we can achieve very thick and hard boride layers on steels
    - Verifying superior mechanical and tribological performance
    - Successfully boriding some of the representative engine parts, like piston pins and rings.
- **Collaborations:**
  - Excellent working relationships have been established with Bodycote which is one of the largest heat-treatment companies in US. Several automotive part suppliers are also supporting our work by supplying materials and additional test facilities.
- **Future Directions:**
  - Concentrate more on actual engine parts.
  - Optimize process conditions and develop reliable boriding protocols.
  - Approach additional companies for partnership and technology transfer.