Low-Friction Hard Coatings

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Project ID #PM030

Overview

Timeline

- Start: 10/01/2006
- Finish: 09/30/2013
- % Complete: 85%

Budget

- Total project funding
  - DOE - $1,200K
- Funding received in FY10 - $200K
- Funding received in FY11 - $ 250K

Barriers

- Barriers addressed:
  - Efficiency and durability
  - Performance
  - Manufacturability
- Target:
  - Develop low-friction and superhard coatings to achieve superior efficiency and durability in automotive and heavy vehicle propulsion systems

Partners

- Galleon International – Technology Maturation
- Hauzer Techno Coating – Coating process development and scale-up
- Several engine OEMs, including transaxle and fuel injection system manufacturers, engine part suppliers, racing teams, and car manufacturers
- Lead: Argonne National Laboratory

Objectives

- Design, develop, and implement low-friction and super-hard coatings to increase fuel economy, durability, and environmental compatibility of advanced engine systems.
- Demonstrate large-scale manufacturability of such coatings at reasonable cost.
- Characterize and verify coating performance through bench-top, fired-engine, and field studies.
- Transfer optimized technology to industry.

Milestones or Go/No-Go Decisions

- **FY10:**
  - Go/No-Go Decision: Complete remaining field and performance studies. Demonstrate full-scale processing of large numbers of tappets and piston pins. (Passenger car engine tappets, fuel delivery systems, and transaxles are selected as a target product in FY10, and motored engine tests represent industry-accepted field tests.)
- **FY11**
  - Go/No-Go Decision: Complete engine tests, quality control and reliability studies, scalability and cost-benefit analysis. Initiate pilot-scale production and long-range fleet studies in actual engines.

Approach

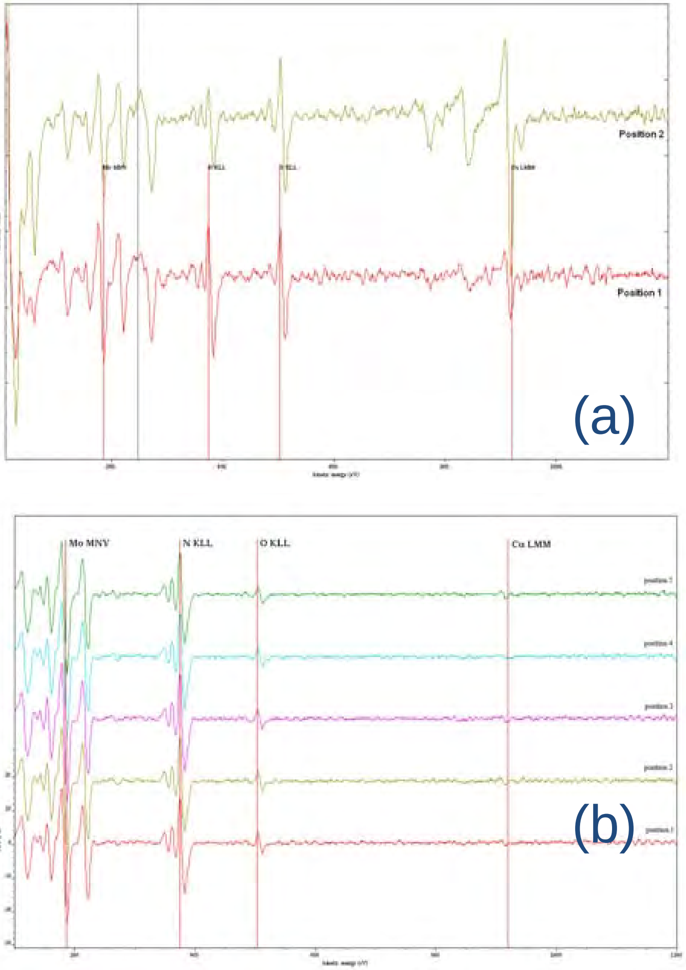
- Identify and optimize deposition conditions that are most critical in physical, mechanical, and tribological properties of superhard and low friction coatings.
- Develop reliable deposition protocols for large-scale manufacturing of MoN-Cu and near-frictionless diamondlike carbon coatings.
  - Confirm superior bonding and surface smoothness.
  - Confirm super-hardness and low friction.
  - Confirm extreme resistance to wear and scuffing under prototypical conditions.
- Demonstrate durability and performance in engine applications.
- Demonstrate large-scale production, cost competitiveness, and commercial viability.

Technical Accomplishments/Progress/Results (Process Optimization)

- Further optimized deposition conditions to achieve much stronger bonding, smooth surface finish, and uniform coating chemistry and thickness on coated engine parts and components.
- Validated large-scale manufacturability of optimized coatings in commercial-scale deposition systems with our coating partner.
- Demonstrated batch-to-batch repeatability of coating quality and performance.
- Coated several engine components (tappets, cam shafts, rocker arms, piston rings, and piston pins) and delivered them to multiple OEMs and automotive companies for internal evaluation and engine testing.

Technical Accomplishments/Progress/Results (Product Optimization)

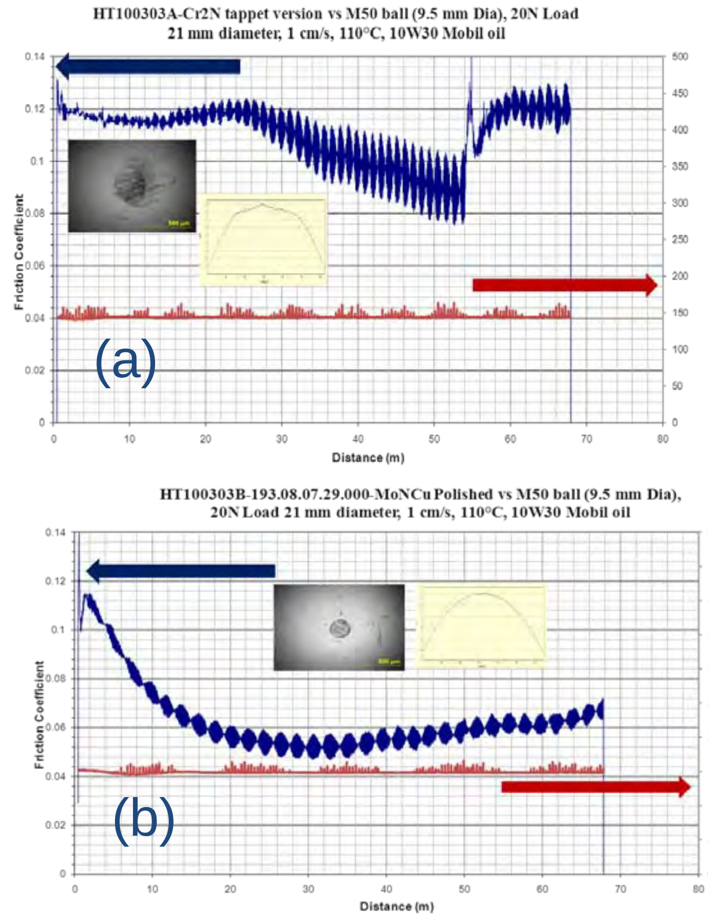
- Developed and implemented surface conditioning protocols to achieve smoother surface finish with chemistry that yields very low friction and wear from the very beginning.
  - Some earlier coatings underwent unwanted copper oxide enrichment toward the surface. We solved this problem by designing better sputtering targets and briefly polishing off the top layer.
  - As shown in the Auger electron spectra, the peaks responsible for copper and oxygen diminished with the new protocol, and these novel coatings provided much lower friction and wear in actual engine tests from the very beginning.
- Filed a new patent application on surface conditioning method (ANL-IN-10-008). Granted US patent (7,846,556) on modulated composite surfaces that combine low-friction and superhard coatings with different surface textures and modulations.



Auger electron spectra taken from the top surface of SHNC coatings: (a) before polishing, showing high levels of oxygen and copper, (b) and after polishing.

Technical Accomplishments/Progress/Results (Bench Studies)

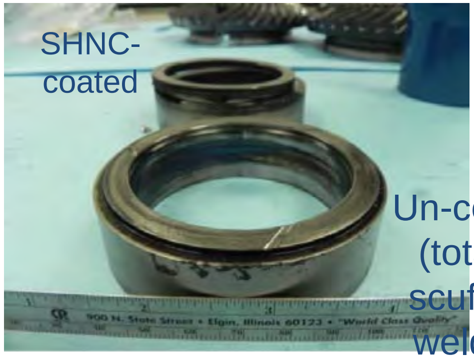
- In bench-scale tests, compared different types of competing coatings (e.g., CrN and DLC).
  - The friction and wear performance of the SHNC coating was much superior that that of CrN at temperatures up to 110 °C. The CrN coating exhibited 40 to 50% higher friction and abrasive wear marks on sliding surfaces after the tests (see figures on right).
  - With respect to the best DLC coating used by industry, SHNC provided similar friction coefficients in fully formulated engine oils but showed no sign of wear when tested under severe boundary conditions. In fact, the boundary film formed on SHNC got thicker in the long run, confirming its unique ability to form protective tribofilms on its sliding surfaces, while DLC wore off and did not show any sign of protective boundary film.
  - The performance of SHNC in Fischer-Tropsch and ultra-low sulfur diesel fuels was also impressive. Even under severe loading and at high temperatures, it provided very good anti-friction and wear properties.



Ball-on-disc experiment showing frictional behavior of (a) CrN and (b) SHNC coating at 110 °C with Mobil 1 10W30 (right y-axis, temperature in °C).

Technical Accomplishments/Progress/Results (Fired Engine Studies)

- Completed component-level testing of SHNC-coated engine parts in fired engines with the help of industrial partners.
  - SHNC-coated tappets provided much superior wear performance than DLC- and CrN-coated tappets in long-duration tests. Frictional behavior of SHNC was impressive up to 80 C but slightly inferior to CrN coating at 120 C; CrN suffered significant wear, while SHNC showed no evidence of wear.
  - When tested in a differential of a full-size pickup truck under severe condition, SHNC-coated parts worked better than coating tested before. Without SHNC, the parts in the differential broke, causing the discs to spin at high very speeds and scuff/weld to bottom piece (see picture on right)
  - In fired engine tests under severe/starved lubrication conditions, uncoated pins suffered severe wear, while no wear was detected on SHNC-coated pins.
  - In initial screening in actual high-speed hot engine tests, SHNC-coated piston rings readily induced severe wear on uncoated and DLC-coated rings. SHNC-coated rings showed no sign of wear. Friction reduction and fuel economy benefits of SHNC are being evaluated in field/fleet tests.



Technical Accomplishments/Progress/Results (Technology Transfer-Implementation)

- Licensing discussions are in the final stages with our industrial partners.
  - Terms sheets have already been prepared, and most of the conditions have been met for final agreements.
  - Sub-licenses are also being negotiated with several engine companies, part suppliers, racing teams, and other OEMs.
  - One new patent has been granted; another has been applied for.

Future Work

- Validate optimized coating durability and performance in fleets of cars under representative driving conditions (FY2011, 2012).
- Concentrate on piston rings and fuel system components by completing bench-top and field studies in fired engines (FY2011 and 2012).
  - Due to much reduced sulfur in fuels and higher compression and temperature regimes in diesel engines, and to adaptation of very low viscosity (like SAE 0W20) grade oils for higher fuel efficiency, our engine company partners have been complaining about increased wear in piston rings/liners and fuel injector systems.
- Explore and adapt the next generation high-power impulse magnetron sputtering technique to the production of much harder and more adherent coatings.
  - This technique is a latest development in the coatings field and has proven to result in the most desirable kinds of coatings in terms of hardness, smoothness, and bonding to substrates at much lower deposition temperatures.
- Develop new coating procedures to eliminate the need for post-deposition polishing. Control oxygen and copper enrichment in top layer on coating during deposition.
- Finalize licensing agreement.

Summary

- Successful demonstration of SHNC coatings on a large number of actual engine parts using lab- and commercial-scale deposition systems with production-scale loads.
- Verification of superior tribological properties of SHNC coatings in a variety of engine components.
- Validation of superior performance in field and fleet of cars (currently underway).
- Scale-up and commercialization efforts in their final stages.