C. Improved Friction Tests for Engine Materials

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Objectives

- Develop a realistic, engine-correlated laboratory-scale test method to be used in selecting diesel engine piston ring and liner materials, and work with ASTM Committee G-2 to establish it as a standard practice.
- Investigate the effects of new versus engine-conditioned (EC) lubricants on the ability of the new test method to detect small friction and wear behavioral differences in engine materials in a repeatable manner.

Approach

- Review and critique past attempts to develop laboratory tests for piston ring and liner materials.
- Develop a testing protocol for friction and wear in reciprocating, lubricated contacts that simulate key aspects of the diesel engine environment.
- Evaluate sources of engine-conditioned lubricants that can be used to conduct friction tests of piston ring/cylinder material evaluations.
- Work with ASTM, through Committee G-2 on Wear and Erosion, to develop a standard practice for conducting laboratory-scale piston ring and liner friction and wear tests in an EC oil environment.

Accomplishments

- Published a report describing and critiquing past efforts to develop engine-correlated laboratory-scale tests for materials and lubricants proposed for use in both spark-ignition and diesel engines.
- Established an ASTM task group on ring and liner wear and populated the task group with representatives from diesel engine companies, automotive companies, testing machine manufacturers, oil companies, government laboratories, and universities.
- Developed a technique to simulate the surface finish of production cylinder liners on simple test coupons.
- Developed a method to run-in piston rings to provide consistent friction data in bench-scale tests.
- Studied the effects of oil condition on friction using diesel oils generated in standardized engine tests.
- A new ASTM standard for friction testing of ring/liner materials was approved and published in FY 2005.

Future Direction

This project was completed in FY 2005. The companion wear standard is complete but has not yet been approved by ASTM. Both standards are currently in use in our laboratory to investigate advanced materials and surface treatments for piston ring and liner applications.

Introduction

Friction between moving parts robs engines of useful energy and lowers the vehicle's fuel economy. Depending on engine speed, the piston ring and liner system in an internal combustion engine can account for over 50% of the total engine frictional losses. New materials, lubricants, and coatings offer the potential to reduce frictional losses; but the development cost for such materials can be high, especially when full-scale engine tests are involved. Smaller-scale, simulative laboratory tests can be a cost-effective alternative for preliminary material and lubricant screening if their results correlate well with the performance of the materials in actual fired engines.

The design of laboratory-scale, simulations of the friction of diesel engine rings and liners is not trivial. Improperly designed simulations can produce misleading results. Tests must enable a proper ranking of alternative materials and lubricants in the same order of merit as they would perform in service. That goal required identifying the mechanical, thermal and chemical influences on friction and wear behavior, and controlling them within a laboratory environment.

By working through ASTM Committee G-2 on Wear and Erosion, this effort has benefited from the diversity of experience of ASTM members. In FY 2001, key elements required for effective ring/liner simulation were identified. In FY 2002, an industry advisory group was formed under the auspices of ASTM committee G-2 on Wear and Erosion. In FY 2003, friction and wear tests were conducted using new and used engine oils to refine the initial test methodology. In FY 2004, based on test results, a draft standard practice was prepared, reviewed by the industry advisory group, and formally submitted for balloting. In FY 2005, the standard practice was approved by ASTM and designated ASTM G-181-04, completing the goal of this project. Work continued on a companion standard for wear.

Description of the Standard

The many technical challenges that had to be overcome in developing the standard practice were described in previous reports; however, selection of suitable, engine-conditioned lubricants was a key element in the final standard. A series of well-characterized diesel test oils were obtained from Southwest Research Institute (SWRI) and used to generate data on which lubricants would provide the varying degrees of aggressiveness needed to screen materials for various types of engines. Results of this work were presented at several meetings and published in the engineering literature (see the Reference list).

The testing machine shown in Figure 1 was modified to hold diesel engine piston rings and liner specimens. The upper specimen holder that oscillates in a heated oil bath was prepared from a production piston from a Caterpillar C-15 diesel engine. At the rear of the photo is the variable-speed motor which is coupled to a Scotch yoke reciprocating drive. The load is applied through a series of linkages below the base platform.

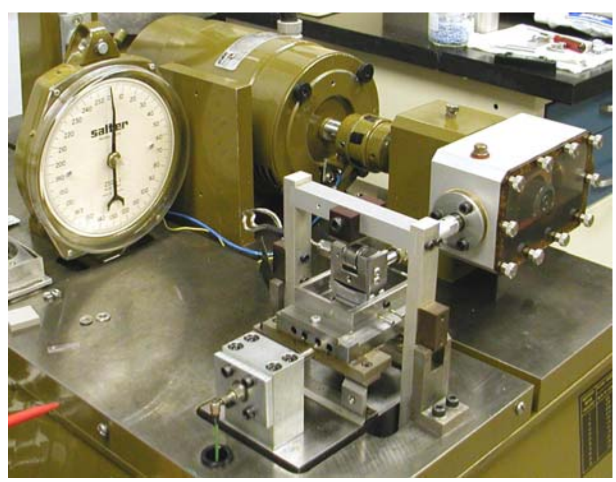

Figure 1. This reciprocating friction and wear testing apparatus was used to develop the new test standard.

The new standard, ASTM G-181-04, is called "Standard Practice for Conducting Friction Tests of Piston Ring and Cylinder Liner Materials Under Lubricated Conditions." It was first published in Volume 03.02 of the ASTM Annual Book of Standards in August 2005 (pp. 748-756) and consists of eleven procedural sections and two appendices of supplementary information.

The first appendix describes a special running-in procedure that was developed to ensure that the ring and liner specimen were accurately mated before the actual data were recorded. Proper running-in is essential to ensure that friction measurements are repeatable from one test to the next. The second appendix describes the process of selecting engine-conditioned lubricants so that results of the friction test can be meaningfully correlated to the performance of the materials and surface treatments in actual engines.

Development of a Companion Standard for Wear

Initially, it was believed that wear evaluations could be incorporated within the friction standard, but in the course of experimentation, it became apparent that there were sufficient differences in procedure for friction and for wear such that the two could not easily be combined in a single document. Therefore, a companion draft standard procedure for wear measurement of piston ring and liner materials was also prepared.

The wear test procedure contains a mathematical procedure to accurately calculate wear volume losses on surfaces with compound curvatures, like piston rings and liners. The derivation, by J. Qu of Oak Ridge National Laboratory (ORNL), enables more accurate wear determinations than are possible using the approximations used by other investigators.

After the new wear procedure had been developed, it was used to study the behavior of candidate light-weight materials and surface treatments. For example, Figure 2 compares the results of a bare titanium alloy and one on which a special oxidation

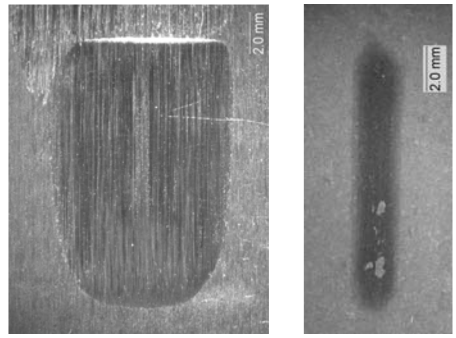

Figure 2. The new ASTM G181 standard was used to study the effects of surface treatments on the friction of light-weight titanium alloys. The specimen on the left is Ti-6Al-4V alloy. The thermally-oxidized Ti-6Al-4Valloy on the right had friction levels similar to those of lubricated cast iron liner material but over 40,000 times less wear than the non-treated titanium on the left.

treatment was applied. The bare specimen on the left ran only 11 minutes in hot oil (but at half the standard test load). The treated specimen of the same alloy, on the right, ran six hours at twice the load on the piston ring.

The draft wear standard was submitted for ASTM Committee G-2 balloting in the summer of 2005, and it is hoped that within the next year it will join its companion as a published standard.

Conclusions

A new ASTM standard for conducting lubricated diesel engine piston ring and liner materials tests was developed and approved. A series of presentations and publications were prepared to describe its development and use to the transportation industry (see below). The new test method can distinguish differences in friction characteristics of diesel oils run under fired engine conditions and will serve as a means to pre-screen new materials and surface treatments for use in energy-efficient engines. A companion standard for wear evaluation is undergoing ASTM balloting.

Within the past year, ORNL has received a number of requests for information on the new standard from automotive and truck engineers as well as from universities that conduct research on internal combustion engines.

Presentations and Publications

1. P.J. Blau (2001) "A Review of Sub-Scale Test Methods to Evaluate the Friction and Wear of Ring and Liner Materials for Spark- and Compression-Ignition Engines," Oak Ridge National Laboratory Tech. Report, ORNL/TM-2001/184, 19 pp.

2. P.J. Blau (2001) "Simulation of Cylinder Bore Surface Finish Parameters to Improve Laboratory-Scale Friction Tests in New and Used Oil," in Engine Systems: Lubricants, Components, Exhaust and Boosting System, Design and Simulation, Amer. Society of Mech. Engineers, ASME ICE Vol. 37-3, pp. 57-63.

3. J.J. Truhan, J. Qu, and P. Blau (2003) "A Rig Test to Measure Friction and Wear of Heavy Duty Diesel Engine Piston Rings and Liners Using realistic Lubricants," presented at 'Conference on Boundary Lubrication for Transportation,' Copper Mountain, Colorado, August 3-7.

4. J.J. Truman, J. Quiz, and P. Beau (2005) "The Effect of Lubricating Oil Condition on the Friction and Wear of Piston Ring and Cylinder Liner Materials in a Reciprocating Bench Test," presented at the 15th International Conference on Wear of Materials, San Diego, and April 2005.

5. J.J. Truman, J. Quiz, and P. Beau (2005) "The Effect of Lubricating Oil Condition on the Friction and Wear of Piston Ring and Cylinder Liner Materials in a Reciprocating Bench Test," *Wear*, Vol. 259, pp. 1048-1055.

6. J.J. Truman, J. Quiz, P.J. Beau (2005) "A Rig Test to Measure Friction and Wear of Heavy Duty Diesel Engine Piston Rings and Cylinder Liners using Realistic Lubricants," *Teratology International*, Volt 38 (3), pp 211-218.

7. ASTM G 181-04 (2005) "Standard Practice for Conducting Friction Tests of Piston Ring and Cylinder Liner Materials under Lubricated Conditions," ASTM Annual Book of Standards, Vol. 03.02, pp. 748-756.