4. ENABLING TECHNOLOGIES

A. Improved Friction Tests for Engine Materials

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Objectives

- Develop a realistic, engine-correlated laboratory-scale test method to be used to evaluate new diesel engine piston ring and liner materials
- Work with ASTM, through an industry-based advisory group, to establish a standard practice for testing the friction of piston ring and liner material combinations.
- Investigate the ability of the new test method to detect small friction and wear differences due to the effects of engine conditioning of the lubricants.

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.
- Study the characteristics of diesel-engine–conditioned oil and determine how to simulate its effects on the friction and wear response of candidate materials.
- Work with ASTM through Committee G-2 on Wear and Erosion to develop and approve a standard practice for conducting laboratory-scale piston ring and liner friction and wear tests.

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 within Committee G02.40 on Non-Abrasive Wear. Populated the task group with representatives from diesel engine companies, automotive companies, testing machine manufacturers, oil companies, government laboratories, and universities.
- Developed a technique for simulating the surface finish of production cast iron cylinder liner bores on simple test coupons.

- Obtained samples of oils run in standardized engine tests and used them to determine the sensitivity of the new test method to delineate lubricant condition.
- Prepared a draft standard practice for ASTM subcommittee review, submitted it for balloting, and revised it based on the results. The revised document is in process of final committee approval.

Future Direction

- Having established the standard, prepare a research report that documents its development, and use the standard to determine the friction of several promising engine ring and liner materials.

Introduction

Friction 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 more than 50% of the total frictional losses in an engine. New materials, lubricants, and coatings offer the potential to reduce such frictional losses; but the development cost can be high, especially when full-scale engine tests are used. Smaller-scale, simulative laboratory tests are an attractive lower-cost alternative, but they are useful only if the results correlate well with the materials' performance in fired engines.

The design of cost-effective, laboratory-scale ring and liner simulations presents a complex challenge. Improperly designed simulations can produce misleading results. Materials and lubricants must be induced to react in tests as they would in actual service. Tests should enable the ranking of alternative materials and lubricants in the same order of merit as they would perform in service. That requires identifying and controlling the major mechanical, thermal, and chemical factors that influence the materials' friction and wear characteristics.

The development of a standard practice through ASTM was thought to be the best way to produce a rigorous friction test for ring and liner materials, one that would meet with industry approval through a consensus voting and approval process. ASTM is an international organization that develops consensus material testing standards. By working through ASTM Committee G-2, Oak Ridge National Laboratory (ORNL) was able to draw on dozens of experienced testing professionals.

In FY 2001, key elements required for effective ring/liner simulation were identified. In FY 2002, the effort was focused on building an industry advisory group and involving ASTM. In FY 2003, friction and wear tests were conducted in new and used engine oils to refine the test methodology and prepare it for the rigorous ASTM standardization process. In FY 2004, the balloting process was conducted. The following section describes this evolutionary process.

Development of the Standard

This formal development of the standard document began with the establishment of a task group on Ring and Liner Wear, by ASTM Committee G02.40, under the auspices of the Subcommittee on Non-Abrasive Wear. In parallel, ORNL researchers began to evolve new laboratory testing procedures and to acquire samples of well-characterized, standard diesel engine test oils from Southwest Research Institute. These engine-conditioned oil samples were comprehensively characterized by sending them to a company that specializes in motor oil analysis.

During that period, decisions had to be made regarding contact geometry, specimen fixturing, cylinder liner surface roughness, surface finish directionality ('lay'), and the use of special running-in procedures to ensure proper specimen alignment. In fact, a special method to simulate the roughness of honed cylinder liners was developed in the course of this work and subsequently published in the *Proceedings of the American Society of Mechanical Engineers, Internal Combustion Engine Division*. Results of reciprocating friction tests on a Caterpillar diesel engine ring and liner combination revealed that the proposed standard could indeed discriminate between subtle changes in the oil condition. This first work was presented in December 2003 at a joint workshop between ASTM committees D-2 (Lubricants) and G-2 (Wear and Erosion).

After an iterative review by task group members, balloting on the draft standard was conducted first at the subcommittee level and then at the main committee level. Results of the latter are scheduled for discussion and resolution at the November 2004 ASTM G-2 Committee meeting in Washington, D.C.

Description of the New Standard Practice

The title of the document is *Standard Practice for Conducting Friction Tests of Piston Ring and Cylinder Liner Materials Under Lubricated Conditions.* It begins with a scope statement, followed by references to other applicable ASTM standards. The terminology section introduces a definition for engine-conditioned oil. The use of engine-conditioned lubricating oil is a key aspect of this practice because it provides the means to evaluate materials under conditions that simulate not only the mechanical and thermal aspects of a ring and liner interface, but the chemical aspects as well.

The basic procedure involves the geometry shown in Figure 1. A piston ring segment oscillates with a load, stroke length, and rate appropriate for the engine of interest. Before the tests are conducted, the surfaces of the ring and liner are worn under low load to seat them properly. Early tests showed that failure to run-in the specimens carefully can increase the scatter and decrease repeatability of the test results.

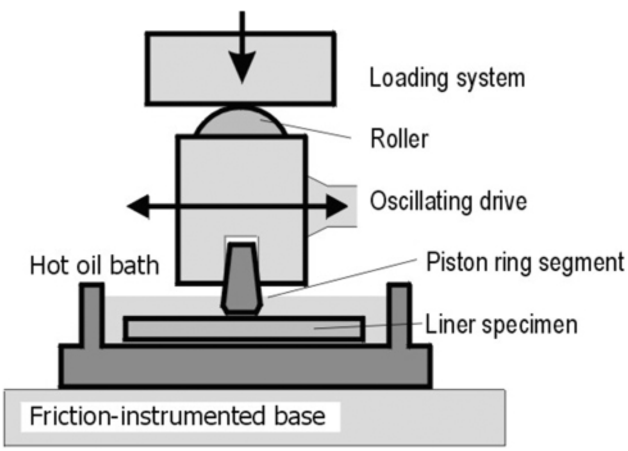

Figure 1. Side view schematic diagram of the ring-on-liner test.

Additional Use for Wear Measurement

The effects of oil condition on wear can also be studied using a variant of this test method. It is known that used engine oil tends to be depleted of its friction-reducing and wear-reducing additives. Such oils also contain soot, a by-product of combustion. The effects of oil condition on wear are illustrated in Figures 2 and 3. Both tests involved the same starting material combination (a chromium-plated diesel engine ring on cast iron). Tests were run for 6 h in oil at 100°C. In the first case, the lubricant was fresh 15W40 grade diesel engine oil (Cummins Blue); and in the second case, the lubricant was a high-soot test oil from Southwest Research Institute (called "M11 HST oil"). Using a surface profiling instrument, the wear volumes and wear rates of the specimens can be determined. In the example shown here, the wear rate of the cast iron in engine-conditioned test oil was four times higher than in the fresh oil. Therefore, as an added benefit, the basic friction test procedures developed in the course of this project can be extended, with minor procedural modifications, to measure the wear of new ring and liner materials as well.

Plans for FY 2005

A workable method for friction testing of ring and liner materials having been established, three remaining tasks are planned for FY 2005:

1. Resolve any negative votes that may arise from the fall 2004 main G-2 committee ballot.
2. Prepare a research report that will be kept on file at ASTM headquarters. This is a society requirement

Figure 2. Wear scar on cast iron produced by 6 h of testing at 240-N load, 10-mm stroke, 10 cycles/s, in fresh 15W40 diesel oil. The normalized volumetric wear factor was 1.9 × 10–7 mm3/N-m.

Figure 3. Wear scar on cast iron produced by 6 h of testing at 240-N load, 10-mm stroke, 10 cycles/s, in M11 HST test oil. The normalized volumetric wear factor was 7.7 × 10–7 mm3/N-m.

that serves to support the technical basis for each new standard.

3. Use the new practice to evaluate a selection of candidate engine materials and surface treatments, thereby demonstrating the usefulness of the standard in supporting other heavy vehicle materials and surface engineering development efforts.

A portion of the experimental findings on which the ASTM research report is to be based has been accepted for presentation at the 2005 International Conference on Wear of Materials and will be published in a special volume of the journal *Wear*.

Conclusions

Coupling a team of industry experts with laboratory experiments, ORNL has been able to develop a useful method for assessing the friction of piston ring and liner material combinations under mechanical, thermal, and chemical conditions that are similar to those in engines. The new method has been shown to discriminate between the frictional behavior of five standard test oils. Test oils can now be selected to evaluate new ring and liner materials under different degrees of lubricant deterioration and wear severity. A standard practice for lubricated diesel engine piston ring and liner materials testing is nearing final ASTM approval. Validation of the practice on other material pairs is planned for FY 2005.

Publications

J. J. Truhan, J. Qu, and P. J. Blau, "The Effect of Lubricating Oil Condition on the Friction and Wear of Piston Ring and Cylinder Liner Materials in a Reciprocating Bench Test," accepted for publication in *Wear*.