SELF-LUBRICATING CYLINDER LINER COATINGS

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INTRODUCTION

In-cylinder wear and friction mitigation is essential for high-temperature, low-heat-rejection (LHR) engines. Under these extreme conditions, the piston ring/cylinder liner interface operates at oil-starved conditions. Surfaces Research has developed superior self-lubricating cylinder liner composite coatings containing novel solid lubricants to improve wear and friction under these conditions.

These hard/soft coatings are two-phase, utilizing either metal or ceramic matrices with new solid lubricants. The solid lubricant phase lowers friction; the harder metal or ceramic matrix reduces wear. Our composite coatings successfully decrease both wear and friction in high-temperature oil-starved applications.

COATING MATERIALS AND APPLICATION METHODS

Two proprietary solid lubricants developed by Surfaces Research, SL1 and SL2, were evaluated in composite coatings. SL1 is a mixture of inorganic compounds, oxidatively stable up to 1000°C, which maintains low friction throughout the entire 25° to 815°C temperature range. SL2 is a new organometallic compound, stable above 316°C, which prevents wear of steel much better than graphite, MoS₂ or BN in the presence of oil. Two coating matrices were investigated: a high-Fe hard metal composition and an oxide ceramic mixture.

Two processes were developed to prepare coatings. In the first, the solid lubricant and metal or ceramic matrix powders were co-plasma-sprayed. To obtain reproducible lubricant-to-matrix ratios in the coatings, mixing of separate lubricant and matrix powder streams at the plasma nozzle was much more effective than spraying premixed powder. In the second, the matrix was plasma-sprayed onto the substrate, and the solid lubricant was physically impregnated into the open pores of the matrix coating. Both application methods produced excellent results.

FRICITION AND WEAR TESTS

Coatings were evaluated by pin-on-disk friction and wear experiments at both oil-lubricated and oil-starved conditions at 290°C. Self-lubricating coatings maintained low friction, typical of oil lubrication, long after liquid oil was depleted. Wear was substantially reduced compared to uncoated cylinder materials.

Hemispherical 440C steel pins were loaded against the coatings and immersed in 1-mL of a Surfaces Research Group V-based LHR diesel engine lubricant. Applied load was 44.5 N, sliding speed was 3.5 m/min, duration was 60 min., and temperature was 290°C. At 290°C, the oil pyrolyzed and volatilized during the course of the test. The point of complete oil depletion was evidenced by an increase in friction coefficient. We continued the test after oil depletion.

Friction vs. time for an SL1/metal composite is compared to that for the metal matrix itself in Figure 1. Friction vs. time for an SL2/ceramic composite is compared to that for the ceramic matrix itself in Figure 2.

**Figure 1. Low friction after oil depletion with SL1/metal composite coating.**
Figure 2. Low friction after oil depletion with SL2/ceramic composite coating.

Once the liquid oil was fully depleted, the friction rapidly and substantially increased for metal or ceramic matrices themselves. In contrast, both of the solid lubricant composite coatings maintained steady, low friction long after oil was fully depleted.

Wear rates were lowest overall for 440C sliding against solid lubricant/metal-matrix composite coatings. We selected the SL2/metal composite coating for engine testing.

ENGINE TESTS

Two high-temperature diesel engine tests were conducted on cylinder liners coated with the SL2/metal composite. A screening test was conducted for 13 hours in an 8-hp Deutz single-cylinder engine. A full-scale test was conducted for 200 hours in a 400-hp Cummins M11 six-cylinder engine. Both engines were modified for high temperature by external control of the cooling system. The lubricant sump temperature was 171°C. The top ring reversal temperature was in excess of 316°C. The engines were operated continuously at maximum torque and full throttle.

After the engine tests, the depth of the wear step on the cylinder coating near the top ring reversal position was determined by profilometry, and weight loss of the top piston ring was measured. Wear rates were obtained by averaging values over the test duration.

In the single cylinder engine test of the SL2/metal cylinder coating, the top piston ring was molybdenum-coated and an API CI-4, 15W-40 petroleum-based diesel engine oil was used. Wear rates in this test were compared to those with a chromium oxide cylinder coating in an otherwise identical engine test [1]. The cylinder coating wear rates are compared in Figure 3 and the top piston ring wear rates are compared in Figure 4.

The new SL2/metal composite coating on the cylinder liner reduced both the cylinder liner and top piston ring wear rates by 50%, compared to a chromium oxide coating.

The multicylinder engine used ceramic-particle-reinforced chromium-plated top rings and a Surfaces Research 15W-40 Group V-based LHR diesel engine oil. The average wear rates of the cylinder liners and top piston rings during the 200-hour test are presented in Table 1. Cylinder liner and piston ring wear rates were an order of magnitude lower in the multicylinder engine than in the single cylinder engine.

Comparable data on cylinder liner and piston ring wear rates were obtained from a 400-hour high-temperature test in the same multicylinder engine, using the same lubricant, but with a standard cast iron cylinder liner and chromium-plated top piston ring. The 400-hour test was conducted at lower ring/liner load, 55% of that in the 200-hour maximum torque test reported here. The ring and liner wear rates for the conventional materials would be expected to double under maximum torque conditions. The new liner and ring coatings, however, had 15% lower wear rates.

The new Surfaces Research self-lubricating cylinder coating achieved 50% reduction in cylinder liner and top piston ring wear rates in actual high-temperature engine, compared to either cast iron or a wear-resistant chromium oxide coating.

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REFERENCES