Determining Wear and Friction Properties of Novel Hydrocarbon Lubricants

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Abstract

The costs of friction and wear in mechanical systems due to losses in heat, energy, and material are staggering, and in order to address issues related to friction and wear, new, economical lubricants are being designed that may better protect surfaces in contact motion. In this study, six types of lubricants (three base fluids and three fully formulated fluids) were tested for their friction and wear properties in the boundary lubrication regime using 4-ball and pin-on-disk tests. The 4-ball tests showed no appreciable difference in wear between fluids within the same group (base fluids and fully formulated fluids), and, as expected, the fully formulated fluids demonstrated substantially less wear than base fluids. The pin-on-disk tests offered more insight, showing that fully formulated fluid 2-03 had clearly superior performance among all fluids in reducing wear and friction despite its large variations in wear and friction between trials. There was also a clear increase in tribofilm formation moving from base fluids 1-01 to 1-02 to 1-03. Further testing involving other contact configurations and conditions, as well as lubrication regimes, will need to be explored to better understand these lubricants' properties and their ideal applications.

Introduction and Background

- Tribology – Study of motion, friction, wear, and lubrication[1]
- Friction – Resistance to motion[1]
- Wear – Surface damage or removal of material from one or both surfaces due to contact motion[2]
- The main determinants of friction and wear involve the type of motion (sliding or rolling), speed, temperature, load, environment (humidity, atmosphere, etc.), and lubrication regime[3]

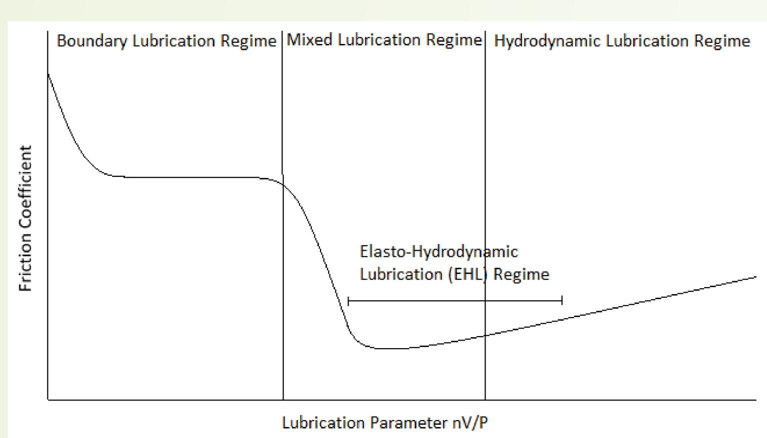


Fig. 1: Schematic diagram of lubrication regimes (Stribeck diagram), where N is the oil viscosity, V is the sliding velocity, and P is the normal load.

- 30% of energy generated in the industrial world is lost to friction, and more than 2 billion U.S.D. per year is lost as a result of wear[1]
- Research and development in tribology can produce benefits of upwards of 50 times the cost of the research[2]
- ***Goal: Evaluate several new, economical lubricants for their wear and friction properties***

Materials

- Sample lubricants – Industrial partner's polyalphaolefin (PAO) lubricants developed from inexpensive, abundant, and sustainable hydrocarbon feedstocks
  - 3 base fluids (1-01, 1-02, 1-03) and 3 corresponding fully-formulated fluids (2-01, 2-02, 2-03)
    - All fluids contain base oil blend formulated using commercial high viscosity base stock (commercial benchmark), including PAO 6 (6 cSt) and alkylated napthylene
    - All fully formulated fluids contain additional chemical additive package at 6 wt. %
    - Each set (1, 2, and 3) has different viscosity modifier
- Measurements performed using Olympus® STM6 Measuring Optical Microscope and Bruker® Contour GT-K White Light Interferometer

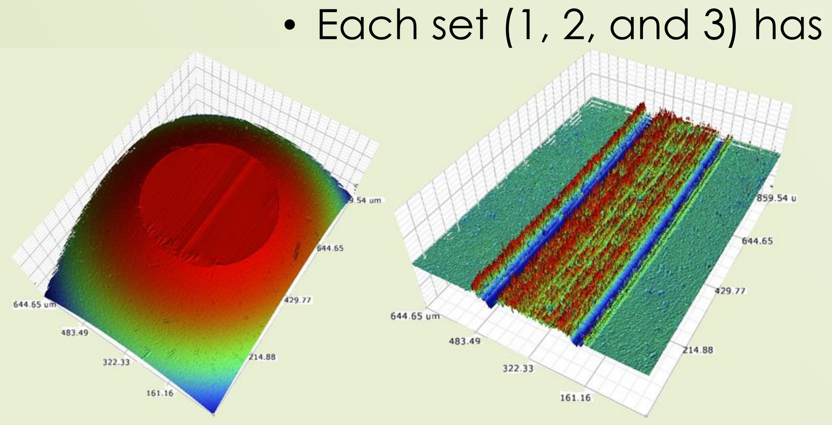


Fig. 2: Sample profilometry images obtained using Bruker® white light interferometer. Wear, tribofilm thickness, and appearance can all be determined using this machine.

Methodology

- ***4-Ball Experiments (3 trials each fluid)***
  - Machine: Falex® Friction and Wear Test Machine
  - Temperature: 75°C
  - Rotational Speed: 1200 rpm
  - Load: 15 kgf, 9.8 GPa (2:1 load ratio)
  - Duration: 60 minutes
  - Sequence: 1 kgf applied after 30 seconds (500 g) followed by 2 kgf (1 kg) every 30 seconds thereafter for a total of 15 kgf (7.5 kg)
  - Motion: Stationary rotating top ball

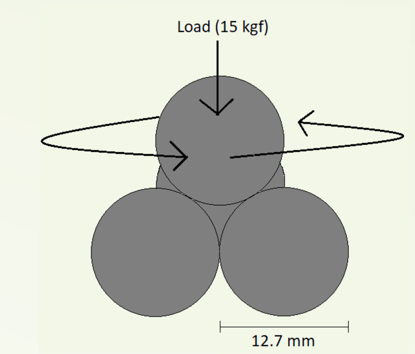


Fig. 3: Schematic of 4-ball experimental set-up.

- ***Pin-on-Disk Experiments (at least 3 trials each fluid)***
  - Machine: Nanovea® High Speed Pin-on-Disk Tribometer
  - Temperature: ~100°C
  - Load: 15 N, 1 GPa
  - Duration: 124 minutes
  - Sequence: Linear speed ramping pattern of 0.1, 0.5, 1, 5, 10, 20 cm/s for two minutes each (12 minutes total), followed by a 60 minute period at 1 cm/s, and ending with same sequence
  - Motion: Unidirectional circular motion

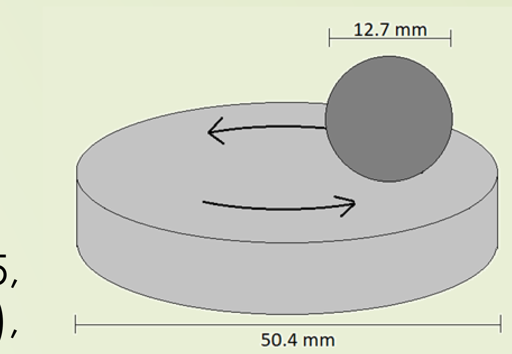
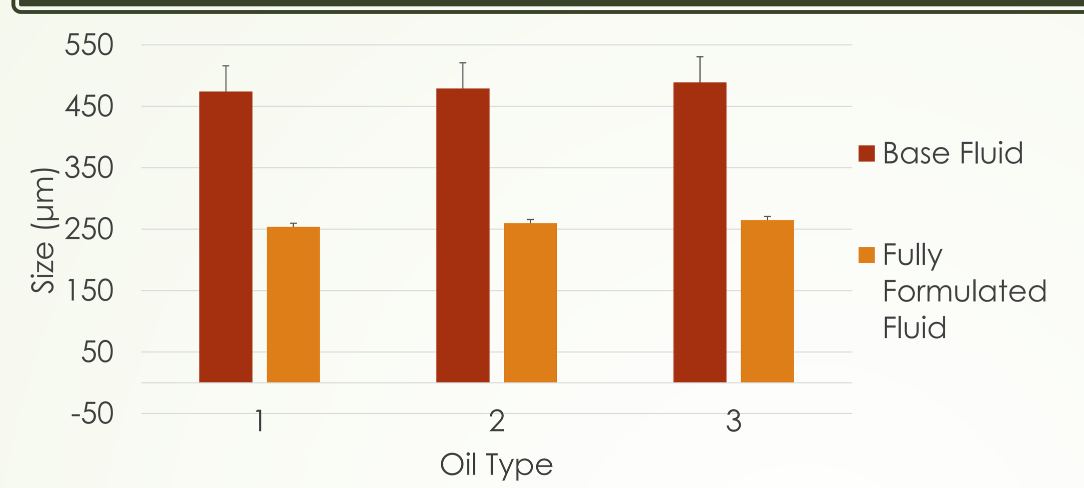
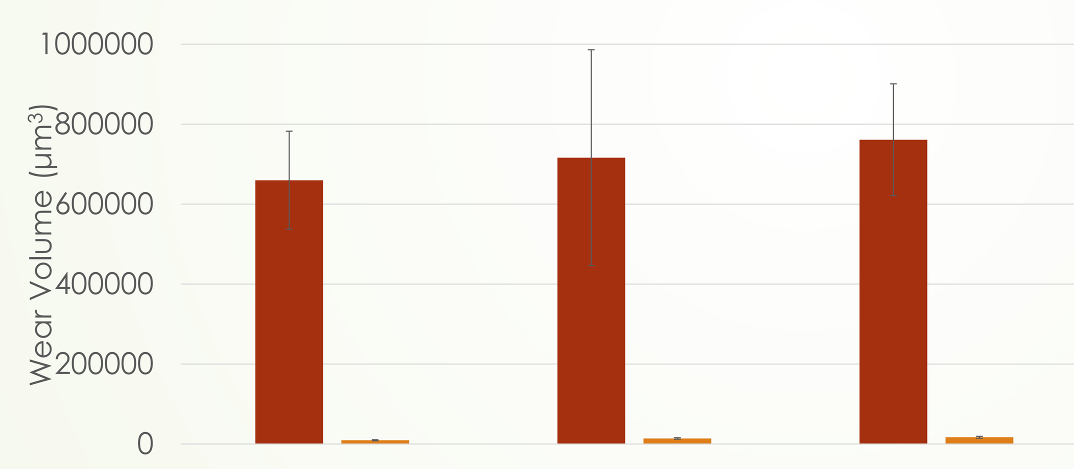


Fig. 4: Schematic of pin-on-disk experimental set-up.

Results



Graph 1: Average scar diameter for lower balls in 4-ball experiments.



Graph 2: Average scar wear for lower balls in 4-ball experiments.

Fig. 5: Optical microscope images of scar wear on representative lower balls (top) and top ball track (lower). All images are at 20X magnification.

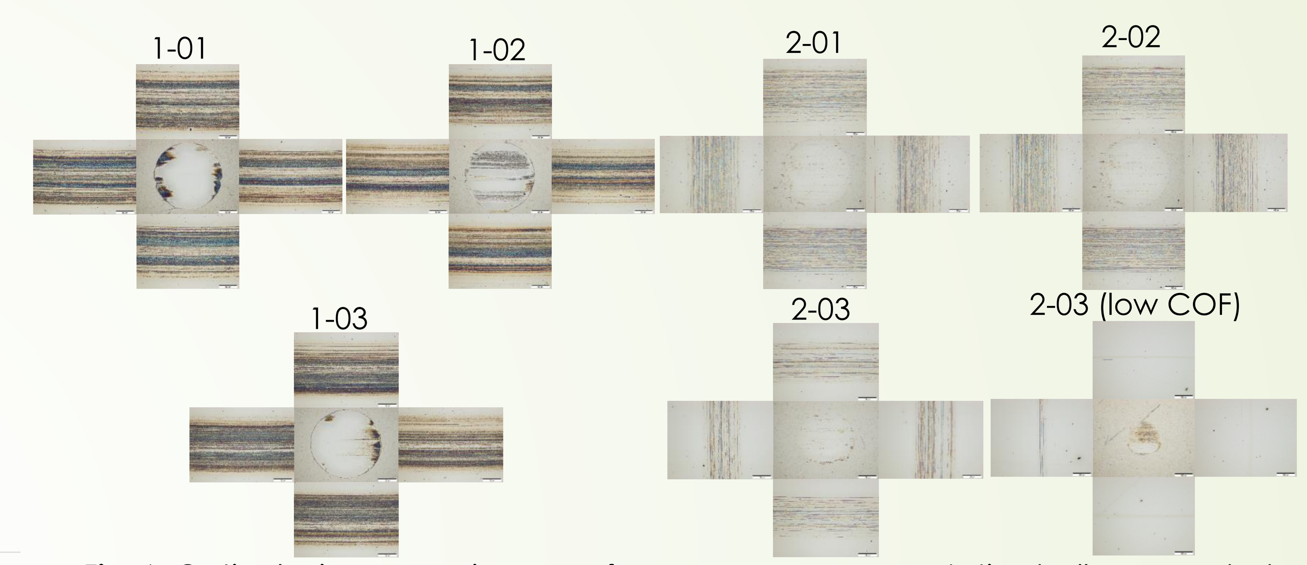


Fig. 6: Optical microscope images of scar wear on representative balls surrounded by the four points on the disk track taken at those locations. All images are at 20X magnification.

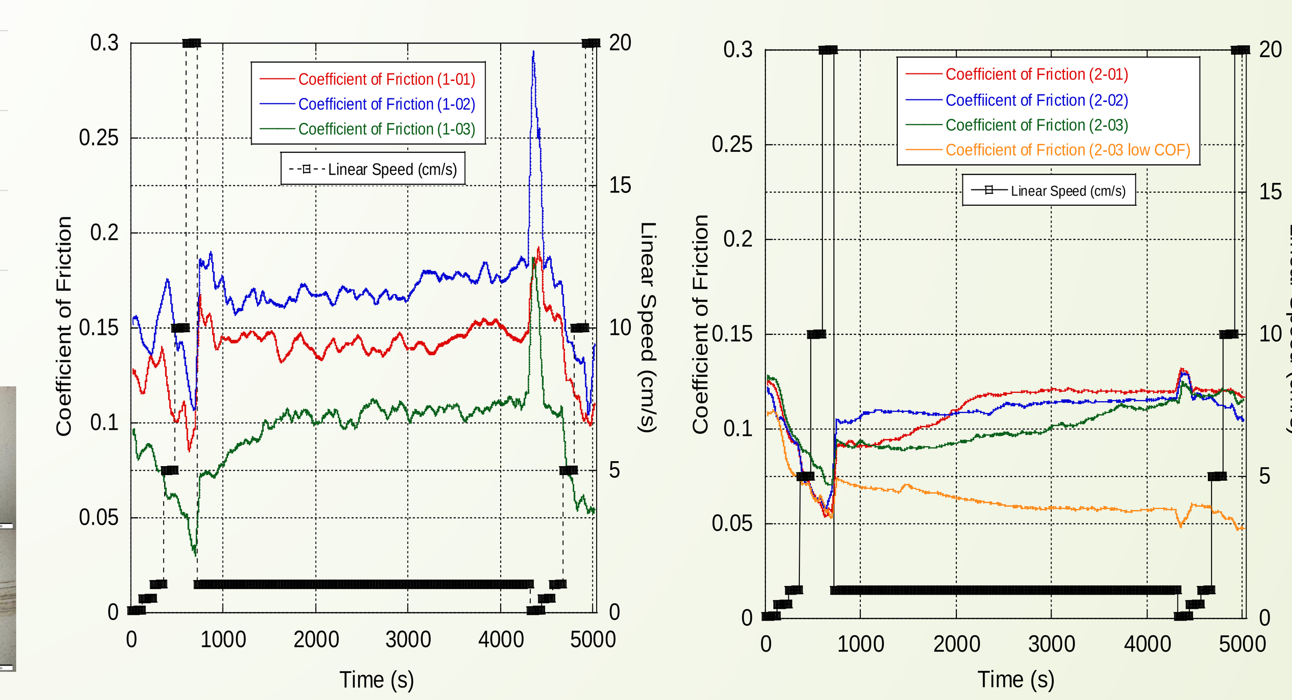
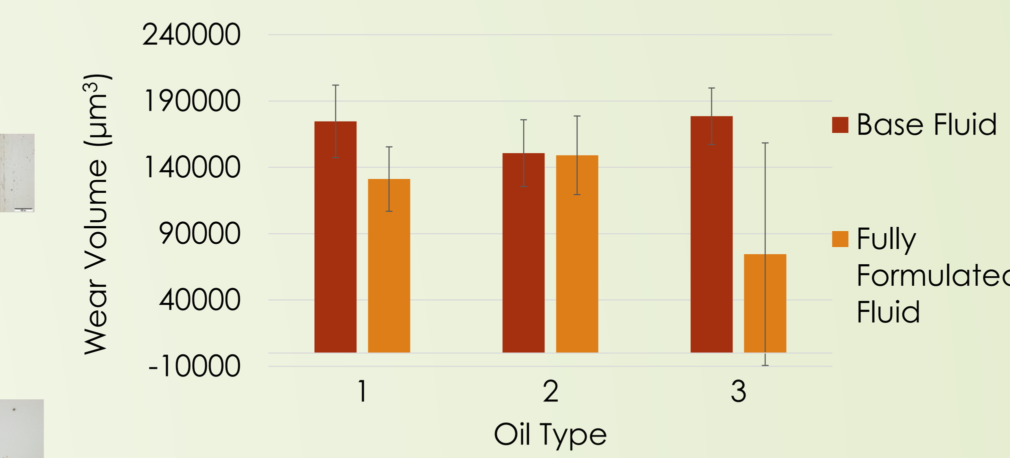
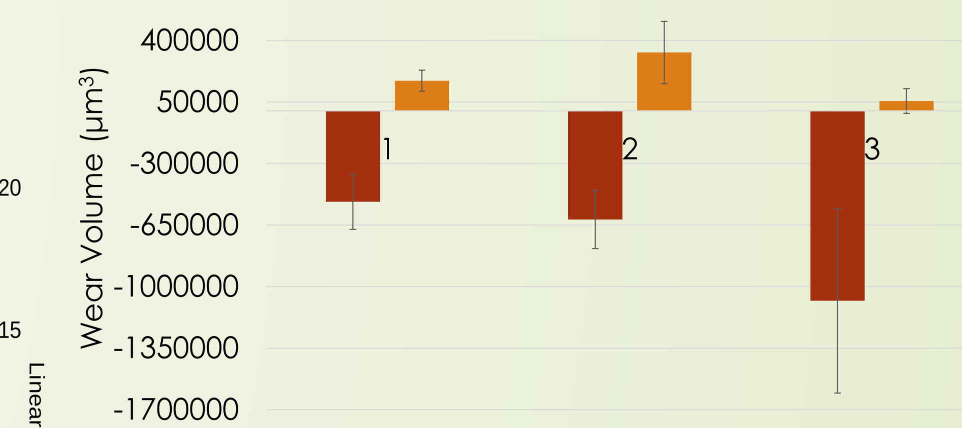


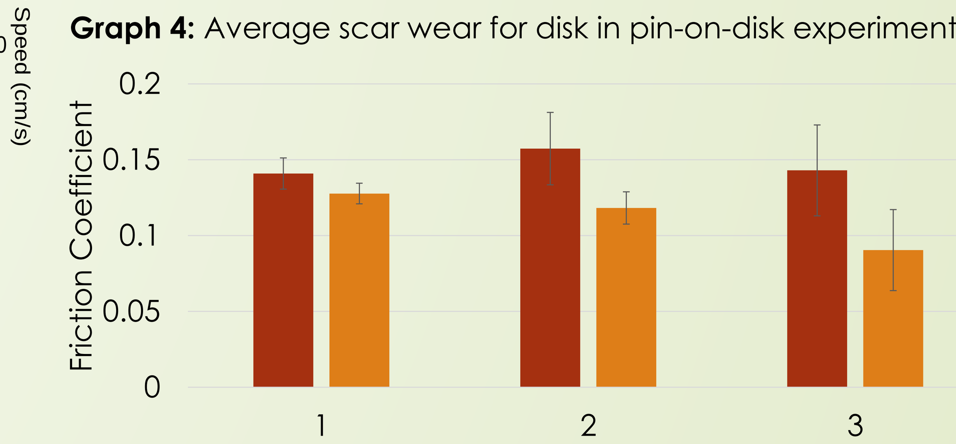
Fig. 7: Representative tests of average friction coefficients during ramping sequence for base fluids and fully formulated fluids for pin-on-disk trials.



Graph 3: Average scar wear for ball in pin-on-disk experiments.



Graph 4: Average scar wear for disk in pin-on-disk experiments.



Graph 5: Average COF for pin-on-disk experiments.

Conclusions and Future Work

- **4-Ball Experiments:** Fully formulated fluids showed noticeable decreases in wear and size of scar diameter as well as amount of wear for the lower balls compared to their base fluid counterparts
- **Pin-on-Disk Experiments:** Ball wear is comparable though fluids 1-02 and 2-01 showing the best performance for decreasing wear with repeatability
  - Fluid 2-03 showed the best performance in wear reduction overall
  - Performance was still largely comparable between fluid types, suggesting that the viscosity modifiers might not be the key determinants of wear
- Viscosity modifiers may play a role in the amount of formation of tribofilm/other material for the base fluids
  - Increase in tribofilm formation is found moving from fluids 1-01 to 1-02 to 1-03
- Comparable average COFs for base fluids, but there is a clear decrease in COF moving from 2-01 to 2-02 to 2-03
- **Future Work:** Different contact configurations, conditions, and lubrication regimes will need to be explored

References

[1]Czichos, H. (1979). *Tribology*. Amsterdam u.a.: Elsevier.
[2]Bhushan, B. (2013). *Introduction to Tribology*. Hoboken: John Wiley & Sons Inc.
[3]Lu, X., Khonsari, M. and Gelinck, E. (2006). The Stribeck Curve: Experimental Results and Theoretical Prediction. Journal of Tribology, 128(4), 789.

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