Tribological Testing and Comparison of Different Lubricants

Farhaan Alam

Hardik Tiwari

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University of Calgary

Abstract

The three-month long internship began with resolving the problems related to the in-house tribometer, which once done was followed by preparing, testing and comparing tribological properties of nanoclay-based greases against other greases prepared in the laboratory, and two commercial greases. All the testing was done on the aforementioned tribometer, which was controlled using labview. Imaging of the wear scars obtained was performed on a standard optical microscope and also on a 3D optical profiler using White light interferometry.

Method

Apparatus Used

The following apparatus was used for sample preparation, reciprocating tests and sample imaging.

A. Sample Preparation

1. Leco GPX Grinding and Polishing Machine.
2. 400 - 1200 grit SiC paper for grinding the sample and polishing cloths for polishing the sample.
3. 9µm - 0.5µm Diamond suspension solutions.
4. AISI 4715 steel samples.

B. Reciprocating Wear Tests

1. Pin-on-disc tribometer, constructed in house.
2. Plain carbon steel rod.
3. Hemispherical sapphire tip (diameter = 6mm)
4. AISI 4715 polished steel samples.
5. Base oil: PAO6
6. Additives: ZDDP, Octopol, Oleic acid
7. Multiple Greases: Dilute C20A greases, with and without oleic acid, Commercial and prepared greases as mentioned later.

C. Wear Scar Imaging

1. Steel sample with the wear scar.
2. Zeta-20 optical profilometer.

3. Leica optical microscope.
4. Profilm Online for cross verifying wear scar depth.

The Lubricants

For the experiments, the following lubricants were prepared:

A. Base oil + C20A
    - Base oil + 0.5% C20A
    - Base oil + 1% C20A
B. Base oil + C20A + Oleic Acid
    - Base oil + 0.5% C20A + 0.05% oleic acid
    - Base oil + 1% C20A + 0.1% oleic acid
C. Base oil + other additives
    - Base oil (PAO6)
    - Base oil + 1% oleic acid
    - Base oil + 1% ZDDP
    - Base oil + 1% Octopol

In addition to these lubricants, the following lubricants were also tested:

- L&G 'red and tacky' commercial grease
- L&G base yellow commercial grease
- Base oil + 15% TOCN + 1.5% C20A + 3.75% oleic acid
- Base oil + 15% TOCN + 1.5% C20A + 7.5% oleic acid
- Base oil + 10% C20A
- Base oil + 10% C20A + 1% oleic acid

Assessments and Measures

We carried out the tests, mostly on an assembled reciprocating tribometer. The apparatus specifications are as follows:

- Plain carbon steel rod.
- Hemispherical sapphire tip. (diameter = 6mm)
- AISI 4715 polished steel samples.

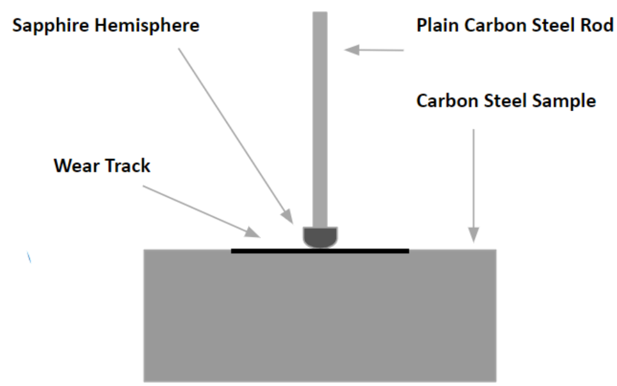


Fig. 1: Schematic representing Reciprocating Wear Test setup

The tribometer was assembled in-house using three linear actuators that had been procured from IntelliDrive. The x-axis actuator is attached to the y-axis actuator, and provides the surface for mounting the sample holder. The z-axis actuator is the vertical actuator, and has the holder for the pin which descends onto the sample. The sample holder is shaped like a 'bucket' which provides a space for us to include our lubricants over the sample surface. A six-axis transducer, obtained from ATI Industrial Automation is placed directly under the holder, such that all the forces experienced by the sample are transferred directly to the transducer. The pin is made from a 3.175mm wide plain carbon steel rod, which is capped by a sapphire hemisphere of 6mm diameter, attached using Gorilla glue. The pin is then inserted and tightened into the holder on the z-axis. To run the test with a specified load, the z-axis actuator descends to the sample surface, with the pin

The apparatus is controlled using Labview, installed on the accompanying computer. All the data obtained from the transducer, routed through an NI DAQ setup, is sent to the same computer through USB. All the linear actuators are also controlled primarily over USB, from the Labview VI on the computer they are connected to. For easier operation in various cases, manual override switches are provided. However, the setup is not perfect, and issues may arise. Please refer to this link for troubleshooting methods of all of the discovered issues:

User manual thingy

All the tests performed were laid out as follows:

Phase 1: Dry tests, base oil only, base oil + ZDDP

Phase 2: Base oil + additives

Phase 3: Dilute C20A greases, with and without oleic acid

Phase 4: Commercial and prepared greases

Phase 1 to 4 were done with a sliding speed of 100mm/s.

The reciprocating tribometer measurements were carried out with the specifications:

- Length of wear scar = 10mm
- Normal load = 20N
- Wear cycles = 3000
- Peak translational velocity = 100mm/s

Results

Phase 1 (the x-axis represents the number of datapoints)

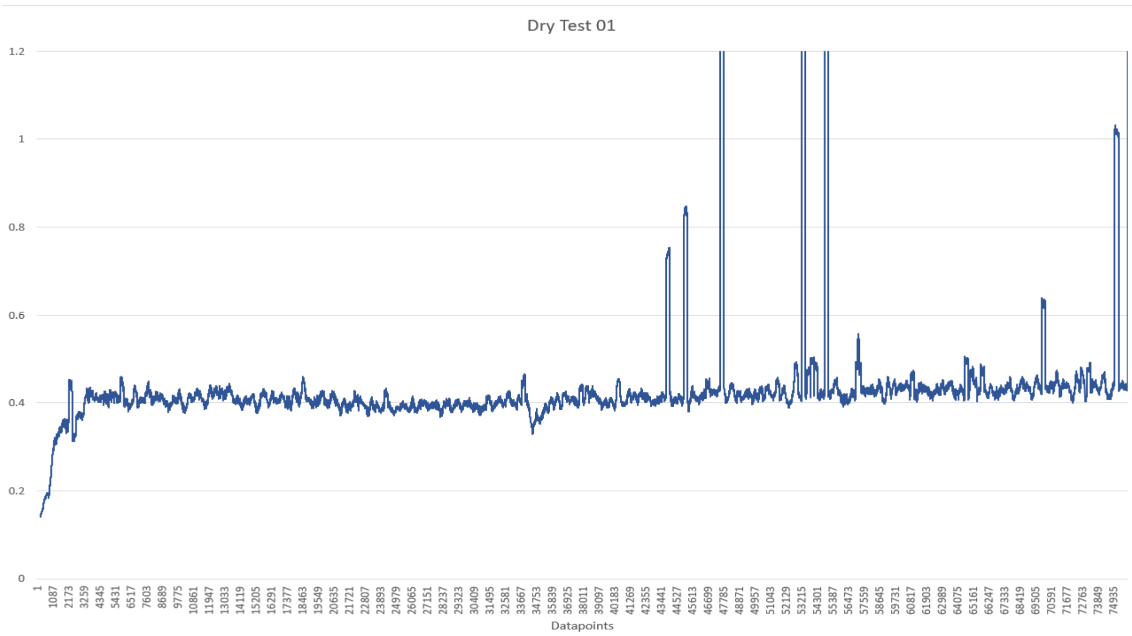


Fig. 2: Friction coefficient plot for the dry test on steel.

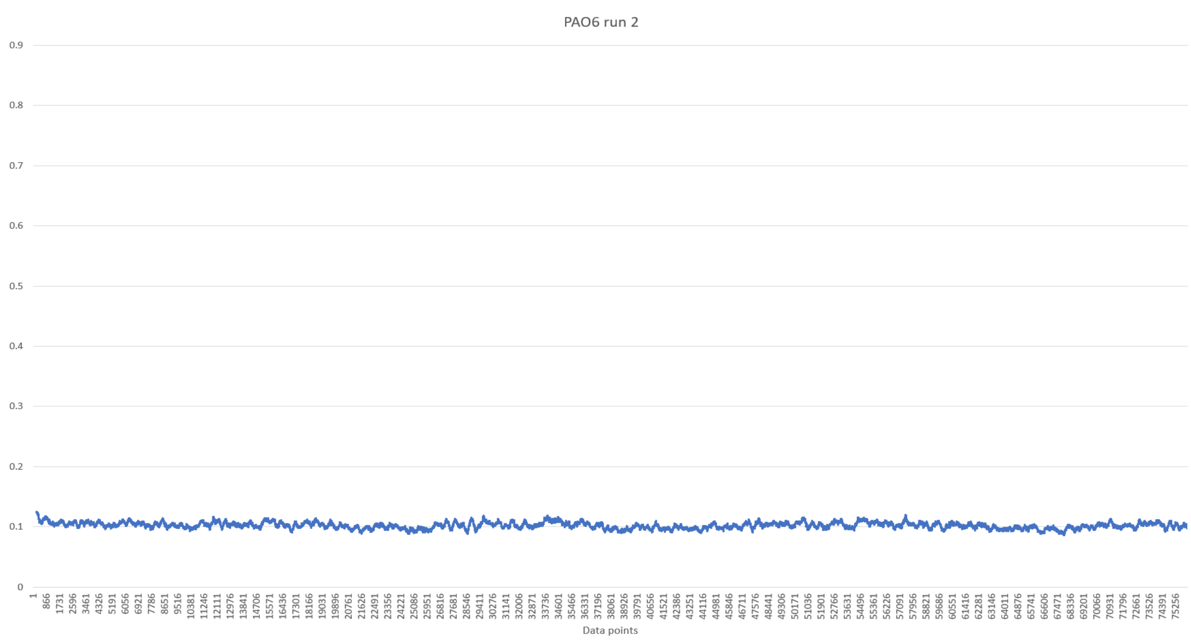


Fig. 3: Friction coefficient plot when the base oil (PAO6) is used as the lubricant.

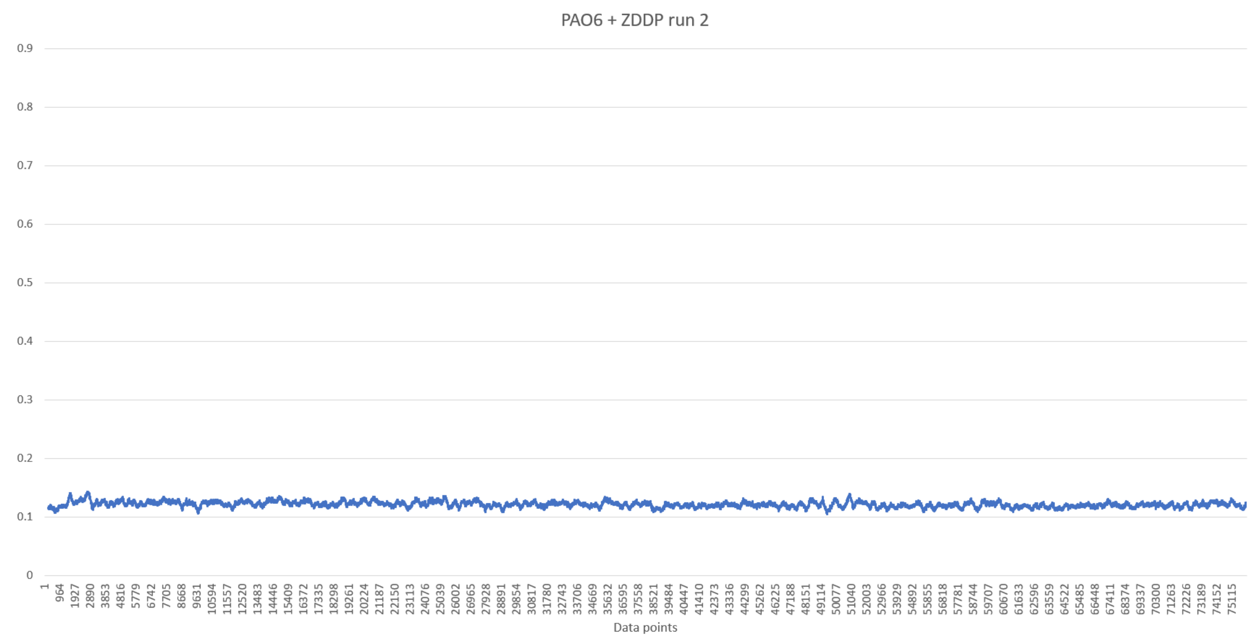


Fig. 4: Friction coefficient plot when the base oil (PAO6) used has 1% ZDDP mixed in.

Inference

- Using a lubricant brought down the friction coefficient by a lot, expectedly.
- Adding ZDDP (an anti-wear additive) to the oil resulted in a marginal increase in the coefficient of friction.

Phase 2 (base oil with different additives)

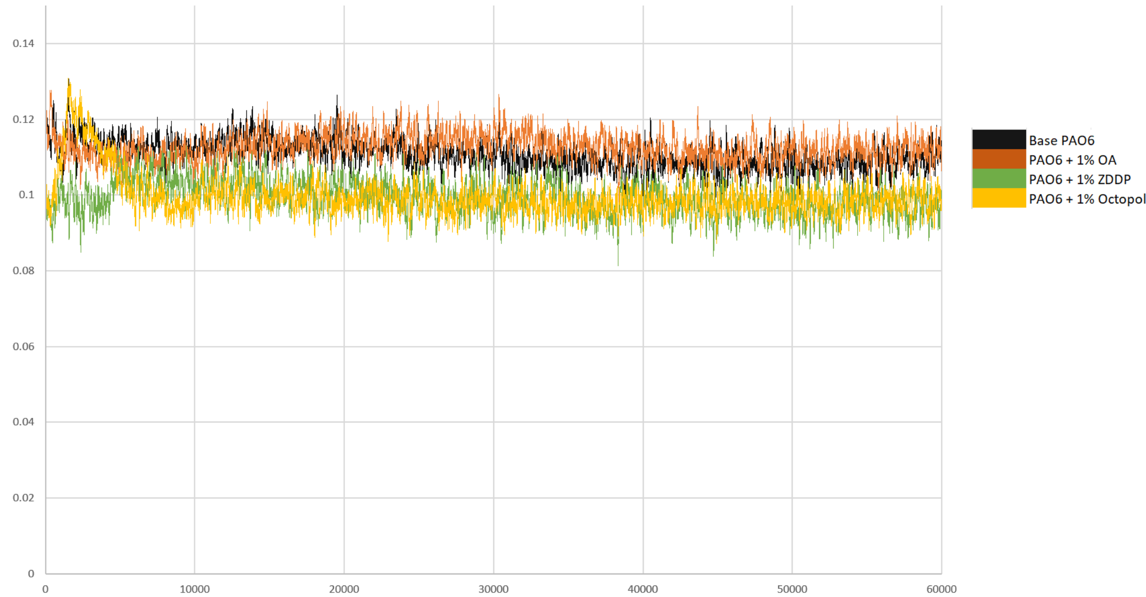


Fig. 5: Friction coefficient plots when the base oil (PAO6) is mixed with different additives.

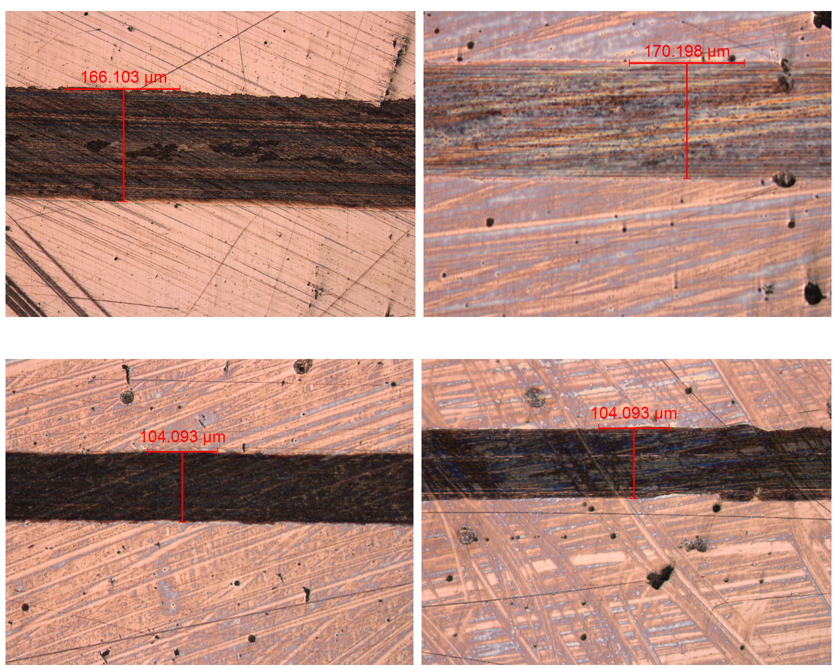


Fig. 6: (from left to right) (scales are not accurate and are to be used to compare the four scars here only)

Row 1: wear scars obtained after 3000 cycles with PAO6 and PAO6 with 1% oleic acid

Row 2: wear scars obtained after 3000 cycles with PAO6 with 1% ZDDP and PAO6 with 1% Octopol

Inference

- Adding oleic acid to the base oil produces negligible differences in friction coefficient and gives a slightly larger wear scar.
- Adding additives Octopol and ZADP (commercially available anti-wear additives) resulted in a much smaller wear scar and slightly reduced friction. Also observed was what appeared to be a film formation on the scar.

Phase 3 (Dilute C20A greases)

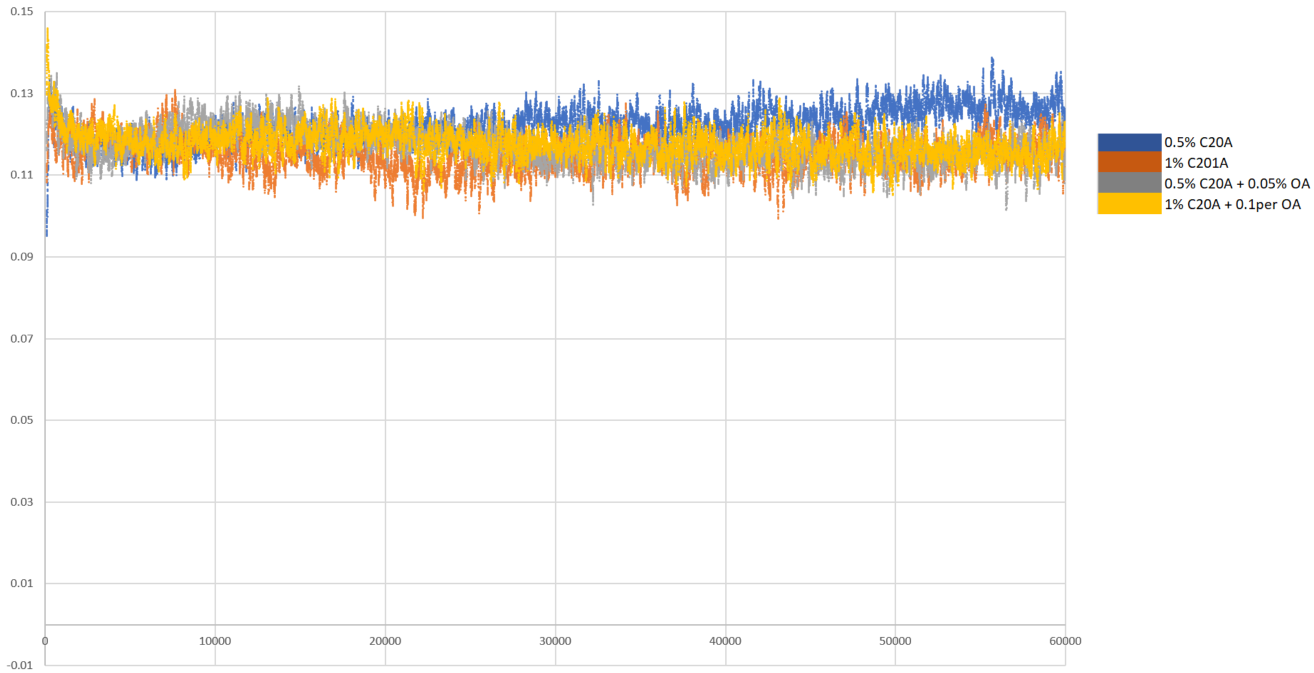


Fig. 7: Friction coefficient versus sliding distance (mm) plots of the dilute greases made with PAO6 as the base oil, and having the nanoclay C20A and oleic acid as additives.

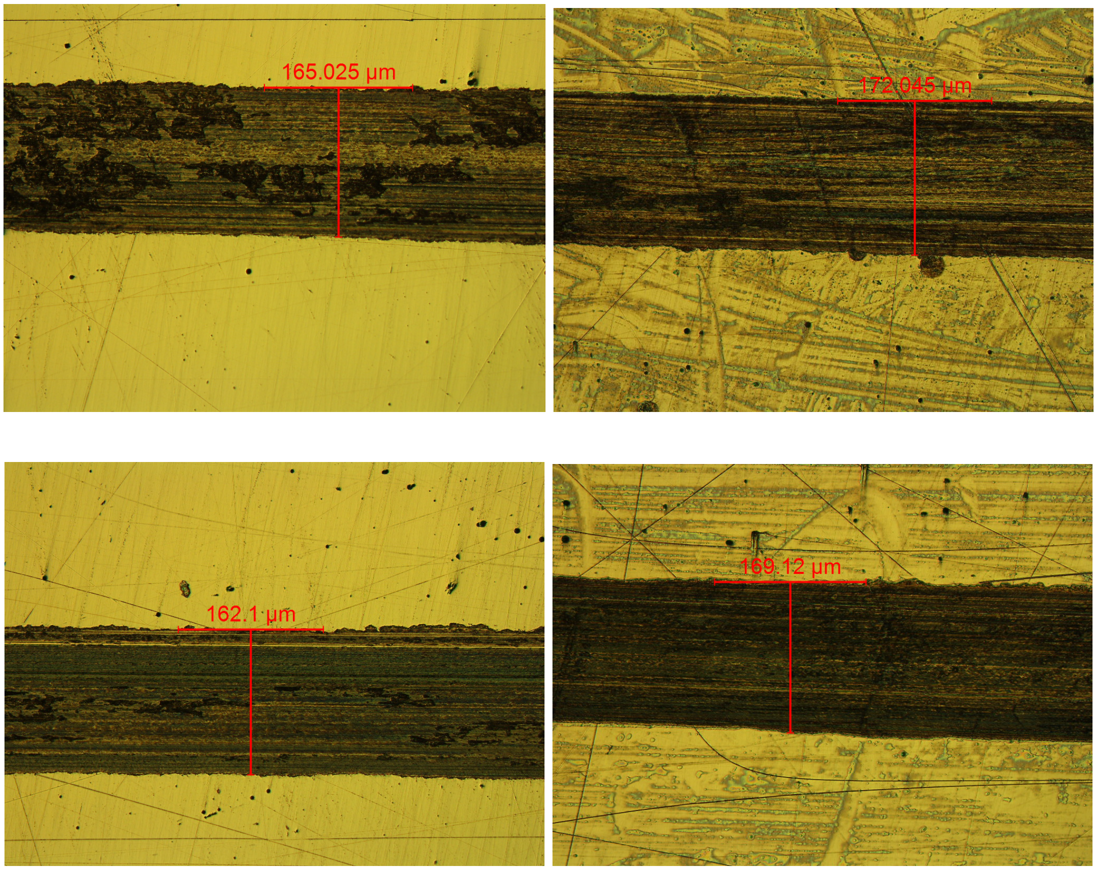


Fig. 8: (from left to right) (scales are not accurate and are to be used to compare the four scars here only)

Row 1: wear scars obtained after 3000 cycles with 0.5% C20A in PAO6 and 0.5% C20A with 0.05% OA in PAO6

Row 2: wear scars obtained after 3000 cycles with 1% C20A in PAO6 and 1% C20A with 0.1% OA in PAO6

Inference

- The general trend observed is that of higher wear with the addition of oleic acid in both the samples.
- Friction coefficients were again, mostly similar, albeit with the sample of 0.5% C20A in PAO6 showing elevated friction coefficients in the later stages of the test.

Phase 4 (Commercial and prepared greases)

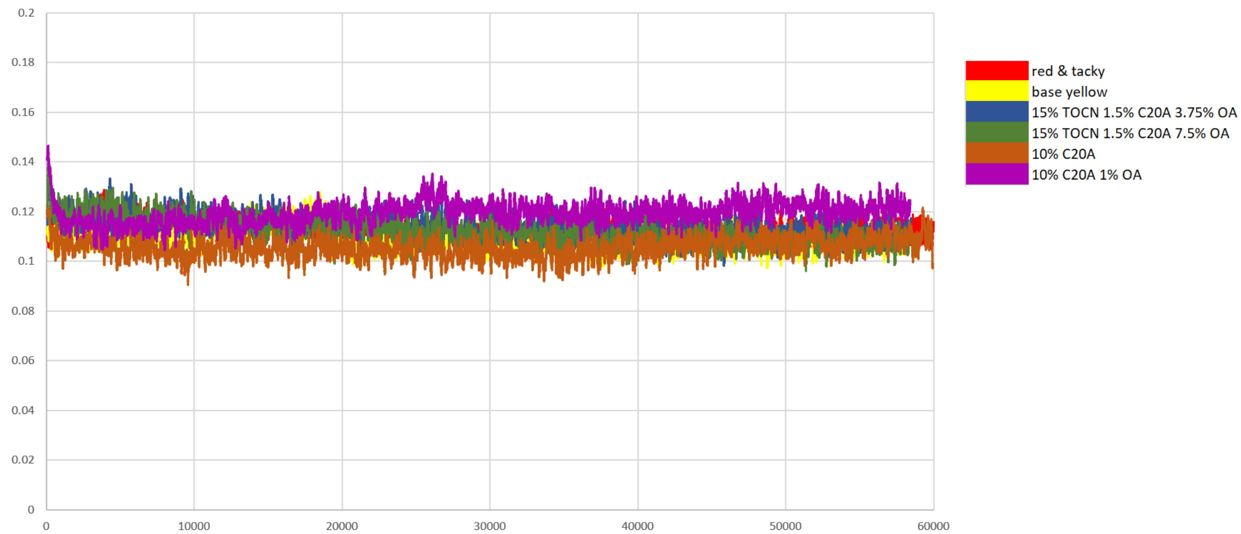


Fig. 9: Friction coefficient versus sliding distance (mm) plots of the two commercial greases, as well as the four prepared greases.

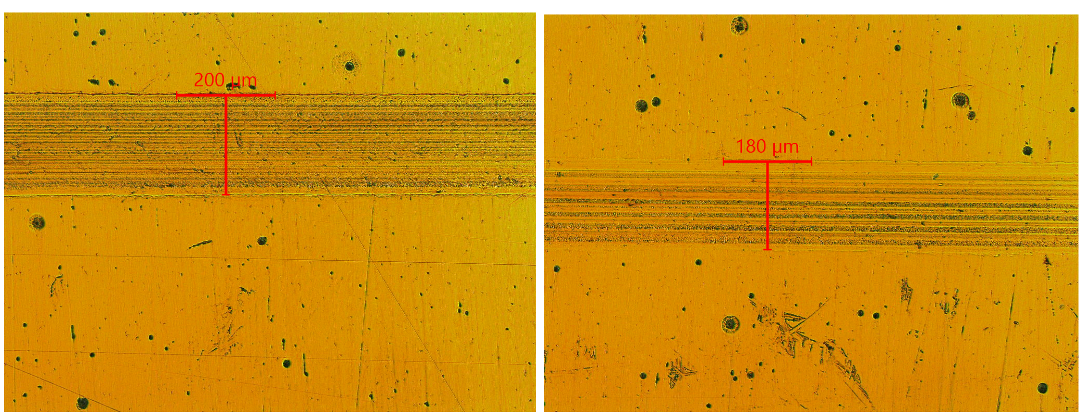


Fig. 10: (left to right) wear scars of the 'red and tacky' and 'base yellow' commercial greases by L&G after 3000 wear cycles.

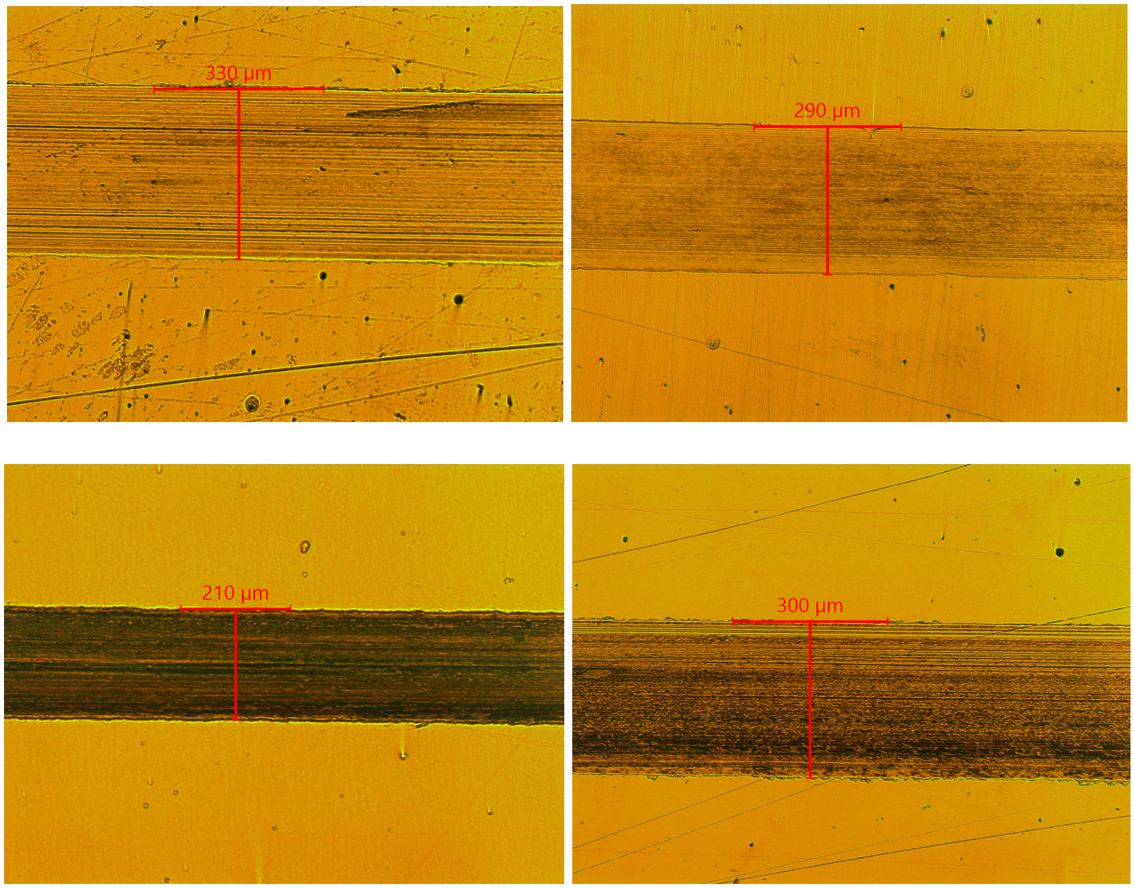


Fig. 11: (from left to right) (prepared greases)

Row 1: wear scars obtained after 3000 cycles with 15% TOCN + 1.5% C20A + 3.75%OA in PAO6 and 15% TOCN + 1.5% C20A + 7.5%OA in PAO6

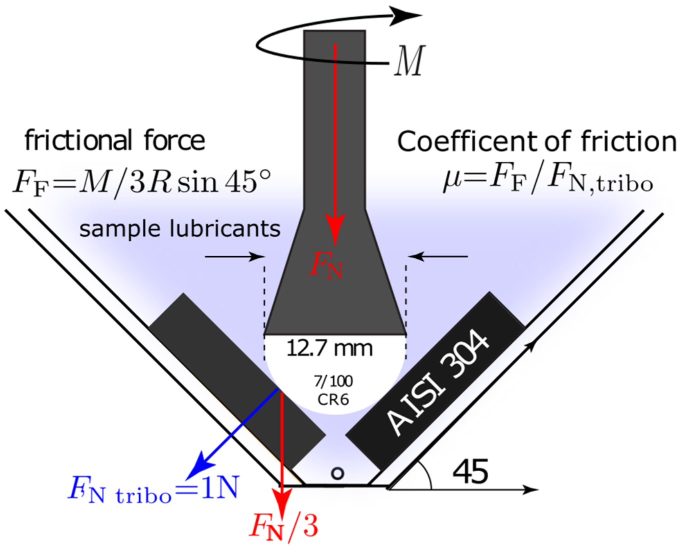
Row 2: wear scars obtained after 3000 cycles with 10% C20A in PAO6 and 10% C20A + 1% OA in PAO6

Inference

- We observe very similar friction coefficient values for all the greases. However, among them, the prepared greases that have OA seem to show a higher value of friction coefficient. The commercial greases appear at the lower ranges of the plot.

- The commercial greases show much lesser wear than the prepared greases. The greases with TOCN show significantly higher wear than the other samples in this test.
- Also observed was a lack of the black film on the wear scars of the commercial and the TOCN greases.

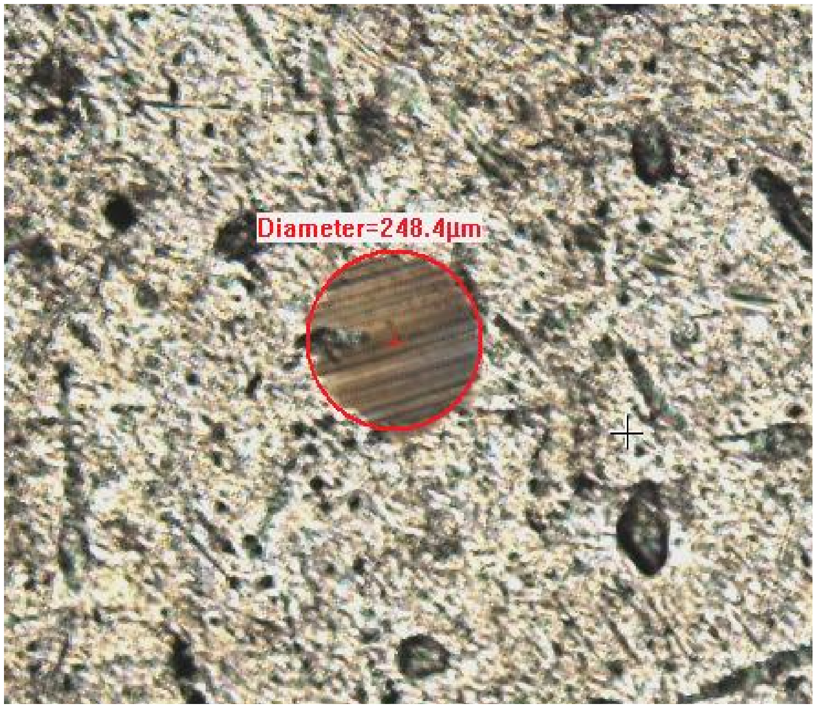
Tests were carried out earlier on the Anton Paar T-PTD 200 Rheometer. The geometry of the tests is as follows:-



Ball on 3 Plates setup
Ref: Enhanced rheological and tribological properties of nanoenhanced greases by tuning interparticle contacts: B. Soltannia

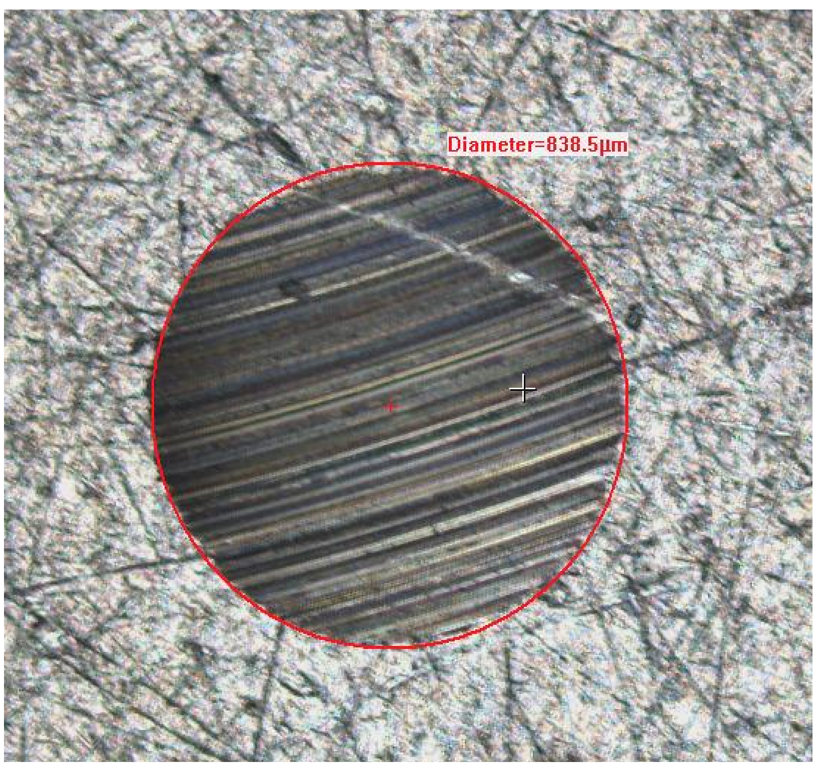
The parameters were the same for all the tests, with the **load on each plate being 2.13N**. Tests were carried out in different phases as follows:-

Test 1: Dry Test, no lubricant.



Wear Scar obtained from the Dry Test

Test 2: PAO6 + 0.1 wt% OA



Wear Scar obtained from the test using 0.1 wt% Oleic Acid

Test 3: PAO6 + 0.5 wt% OA

Wear Scar obtained from the test using 0.5 wt% Oleic Acid

Inference

- Our observations indicate that the introduction of Oleic Acid resulted in a notable augmentation of the wear scar diameter, implying a corrosive effect of the acid on the material.
- Increase in the amount of Oleic Acid corresponded to an increase in the wear scar diameter.
- The following table shows a comparison of the wear scar diameters obtained:

	Dry Test	**0.1% OA**	**0.5% OA**
Wear Scar Diameter	248.4 µm	838.5 µm (+237.56%)	854.0 µm (+243.8%)