Synergy between copper oleate and EP additives: Comparison with fully formulated commercial gear oils

Borja Armendariz | Tekniker | 22/09/2025

Tekniker
MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

Universidad del País Vasco | Euskal Herriko Unibertsitatea
BILBOKO INGENIARITZA ESKOLA
ESCUELA DE INGENIERÍA DE BILBAO

TRIBONEER AWARD 2025

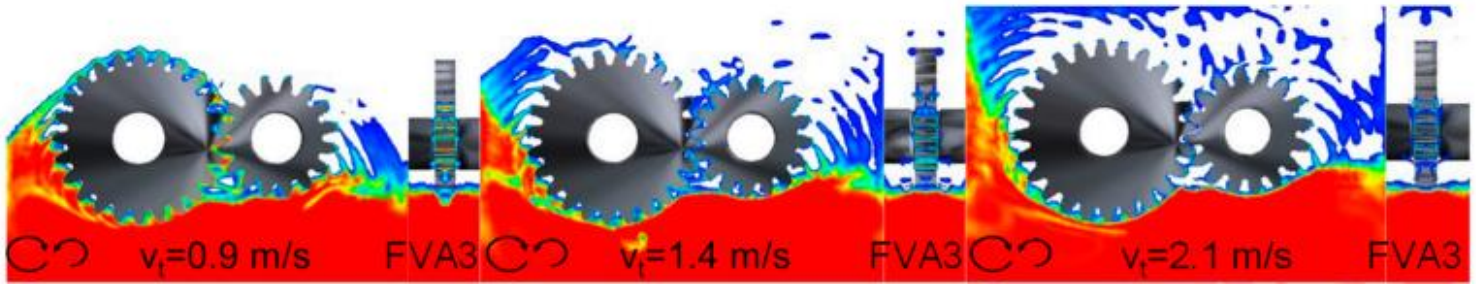
CONTENTS

1

Introduction

1-. Low viscosity oils: efficiency and no-load losses

- In gears and bearings: The reduction of friction is desired to decrease the energy consumption.
- Load independent or hydrodynamic losses: Movement of a component on a viscous fluid.
- These losses increase with rising viscosity and rotating speed → use of low-viscosity lubricants.



[1] H. Liu et al. Detailed Investigations on the Oil Flow in Dip-Lubricated Gearboxes by the Finite Volume CFD Method. Lubricants, Vol. 6 (2018)

1-. Stribeck curve and lubrication regime

- Oil viscosity ↓ Oil film thickness (h_c) ↓
- λ of Taillan:

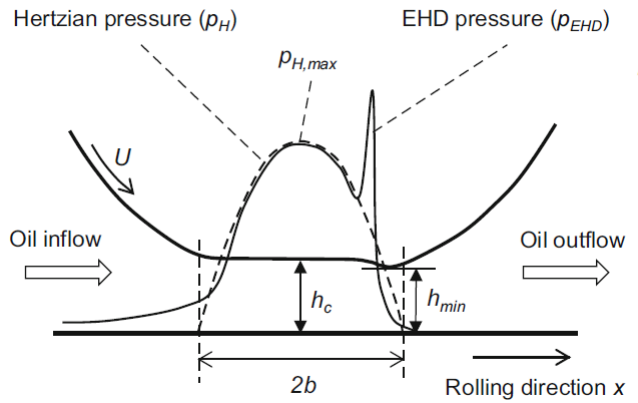
$$\lambda = \frac{h_c}{\sqrt{{R_{q1}}^2 + {R_{q2}}^2}}$$

- Stribeck curve and lubrication regimes:

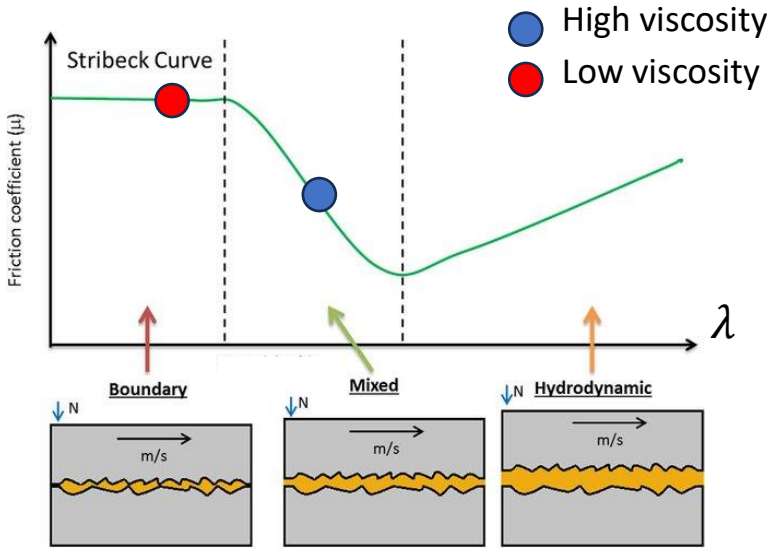
$\lambda < 0.5$ Boundary Lubrication

$0.5 < \lambda < 3$ Mixed Lubrication

$\lambda > 3$ Hydrodynamic Lubrication



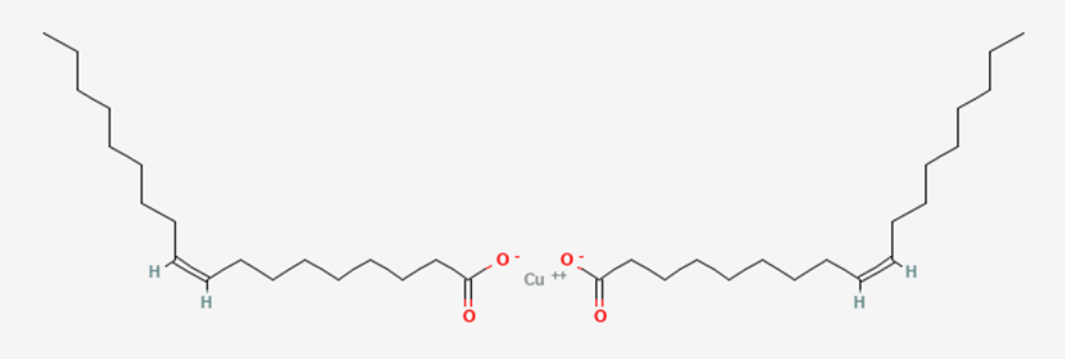
[2] H. Nguyen-Schafer. *Computational design of rolling bearings*. Springer, 1st Ed. (2016)



[3] J. W. Robinson et al. *Probing the molecular design of hyper-branched aryl polyesters towards lubricant applications*. Scientific Report, **6** (2016)

1-. Boundary lubrication: Extreme Pressure (EP) additives and FM → Copper oleate

- EP additives:
  - S, P or Cl compounds included in gear oils.
  - Generate tribofilms when the temperature on the contact is elevated due to extreme pressure.
- FM:
  - Generate tribochemical friction reducing layers.
  - Physical adsorption of polar compounds.
  - Copper oleate generates a low shear strength Cu-based tribofilm.



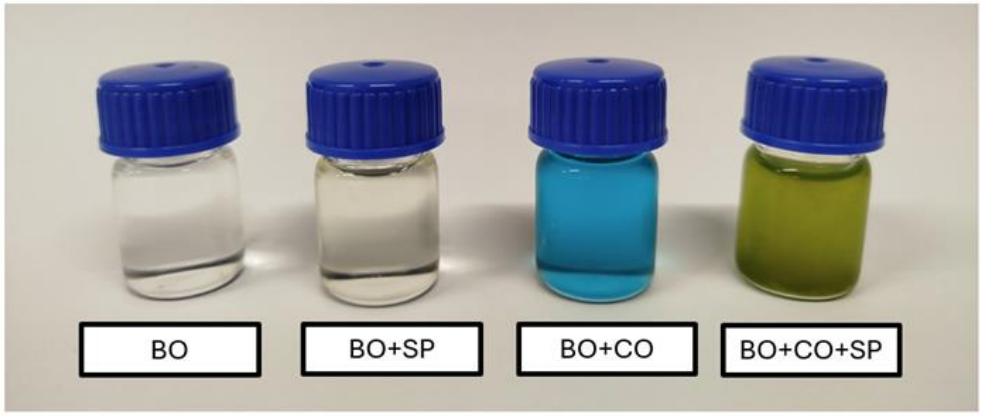
2

Combining copper oleate with EP additives

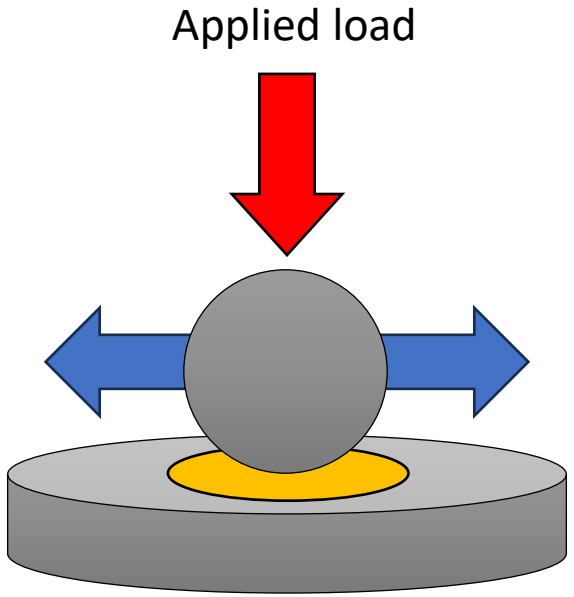
2-. Lubricants formulation

Four ISO VG46 lubricants were tested:

- Base oil (**BO**): PAO8 (93.5 wt.%) + di-ester (6.5 wt.%)
- BO+SP: 2 wt.% commercial Extreme Pressure additive package (P content: 0.97 wt.% and S content: 27.1 wt.%)
- BO+CO: 1 wt.% of commercial Copper Oleate (CO) additive package
- BO+CO+SP: Lubricant that contains both additives on the same quantity to study their synergy.

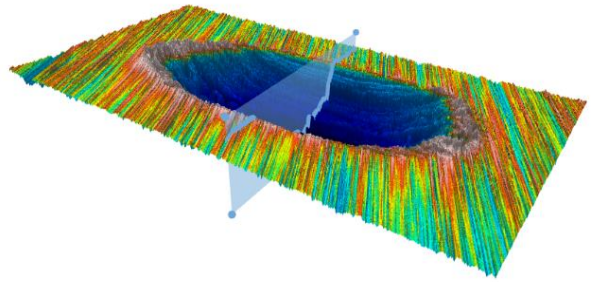


2-. Reciprocal sliding tribological tests: Conditions



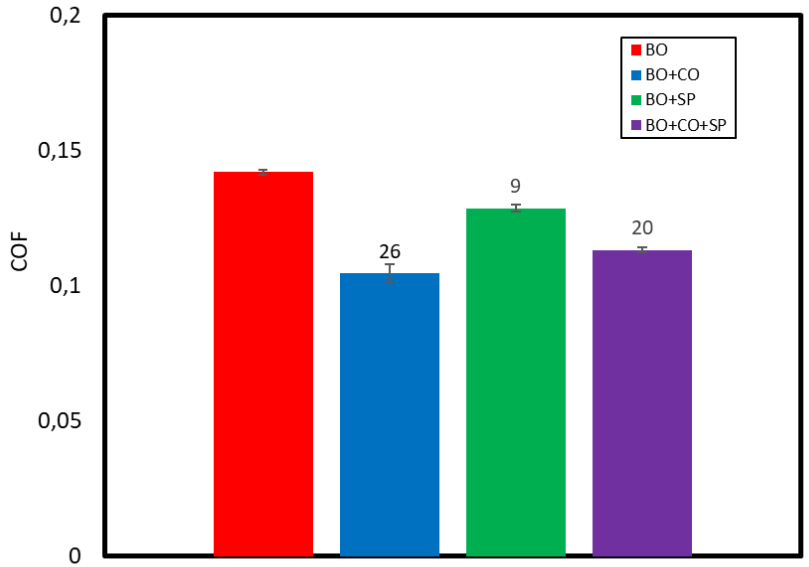
Applied Load (N)	180
Hertz´s Max. Pressure (GPa)	2.7
Stroke (mm)	1
Frequency (Hz)	50
Mean speed (mm/s)	100
Oil temperature (℃)	80
time	120 min
λ	< 0.1

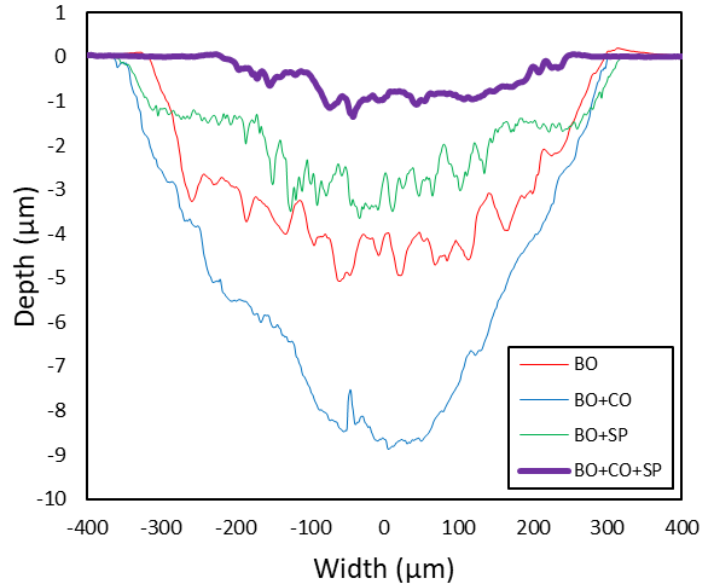
Boundary lubrication



2-. Reciprocal sliding tribological tests: Results

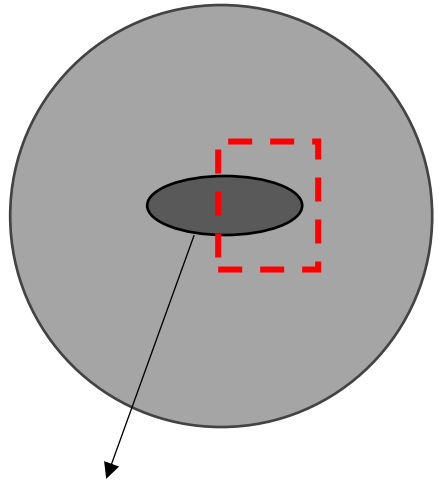
- Introducing CO led to 26% reduction of friction compared to BO. However, the tribofilm generated did not correctly protect the surface.
- SP additive package presented a minor reduction on friction and wear.
- When both additives were combined (BO+CO+SP) → 84% wear reduction compared to BO → Synergy



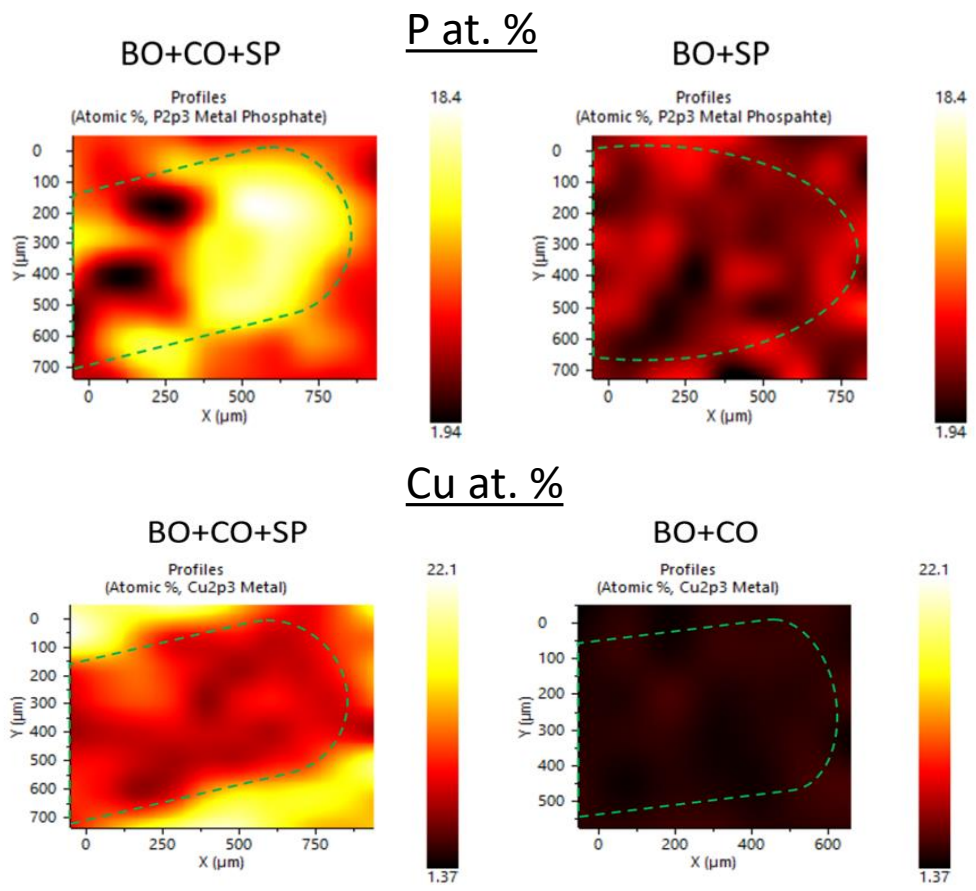


2-. XPS results

Top view of disc after test



XPS results

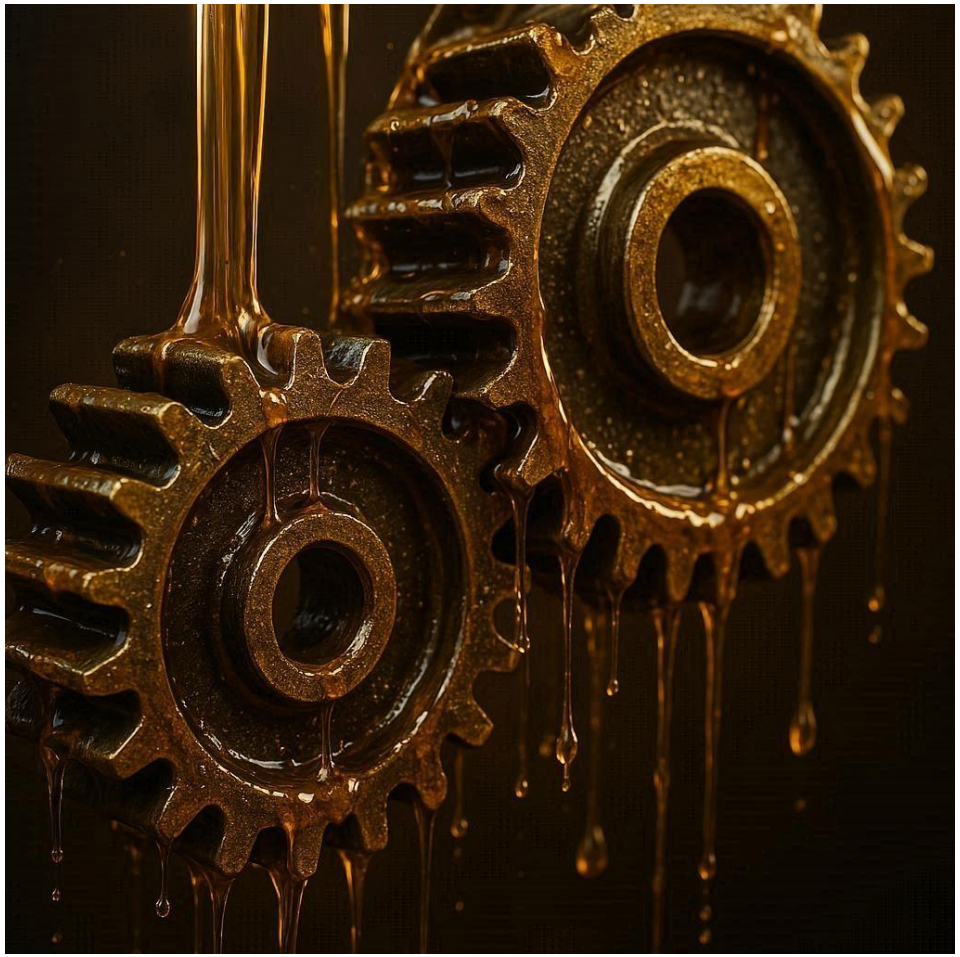


- In BO+CO the at. % of Cu on the surface is negligible. The higher at. % of Cu in BO+CO+SP is remarkable.
- The at. % of P in BO+SP < BO+CO+SP.
- Mechanism: reaction between Cu and S to generate Cu_2S, enhancing the reaction of P to generate robust $FePO_4$ tribofilm.

3

Comparison with fully formulated lubricants

3-. Selection of lubricants



- **PAO320**: Synthetic (mixture of PAO and ester) fully formulated gear oil.
- **MIN320** and **MIN150**: paraffinic commercial mineral-based gear oils.
- **BO+CO+SP**: ISO VG 46 synthetic oil combining copper oleate and SP additive package.

	MIN150	MIN320	PAO320	BO+CO+SP
Kinematic viscosity at 40 ℃ (mm^2/s)	149.8	321.1	308.4	44.5
S content (mg/kg)	8042	15440	3593	4722
P content (mg/kg)	308	274	349	181
Cu content (mg/kg)	0	0	0	646

3-. Twin-disc: concept of traction curves

Mean entrainment speed

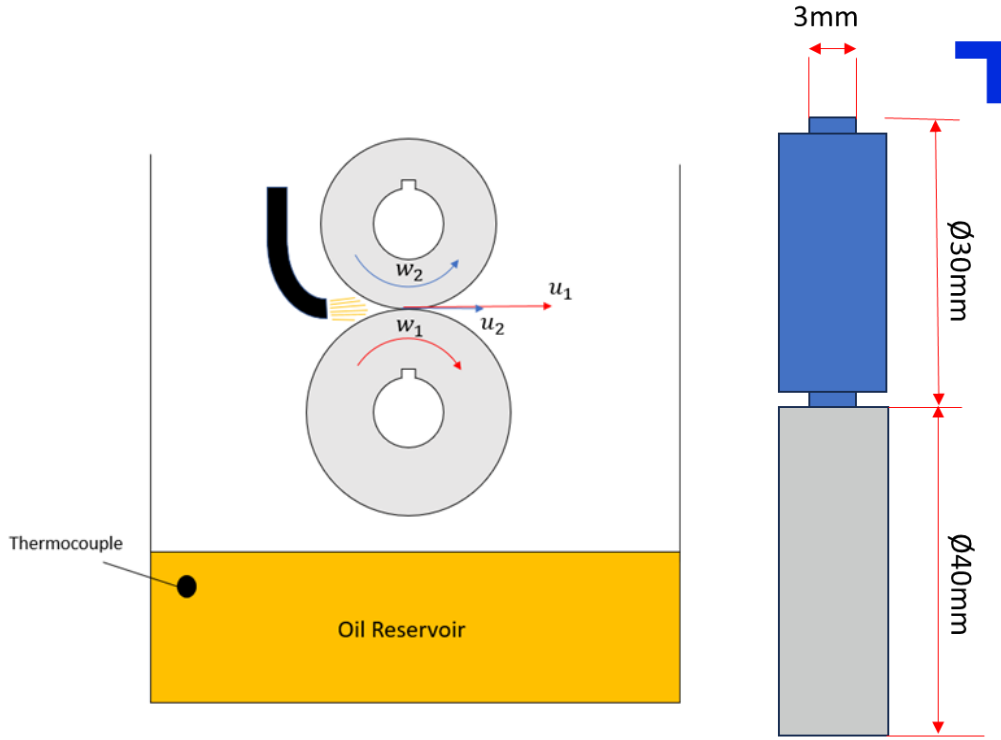
$$u_m = \frac{u_1 + u_2}{2}$$

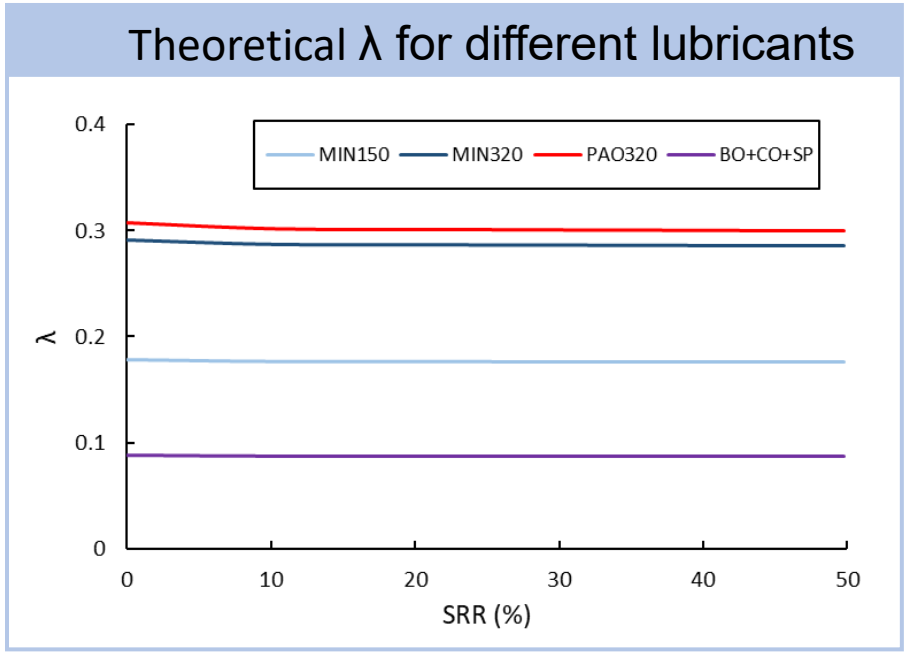
Slide-to-Roll Ratio

$$SRR = \frac{|u_1 - u_2|}{u_m}$$

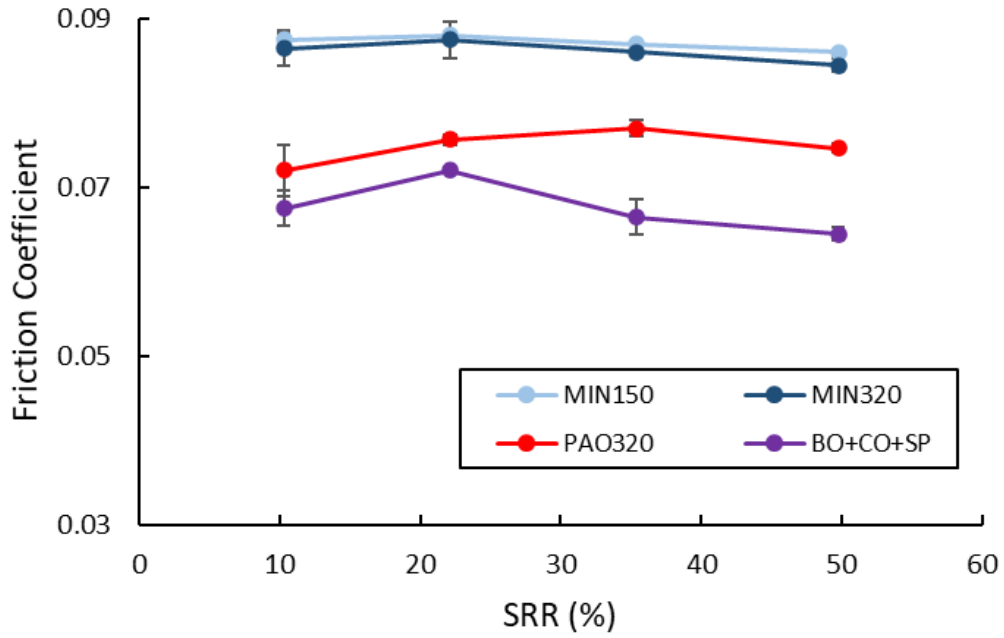
$P_H = 1.5\ GPa$ (LS9 of FZG type C gears)

$u_m = 0.5\ \frac{m}{s}$ is constant while SRR was selected as 10%, 22%, 35% and 50%.





3-. Twin-disc traction curves: Results

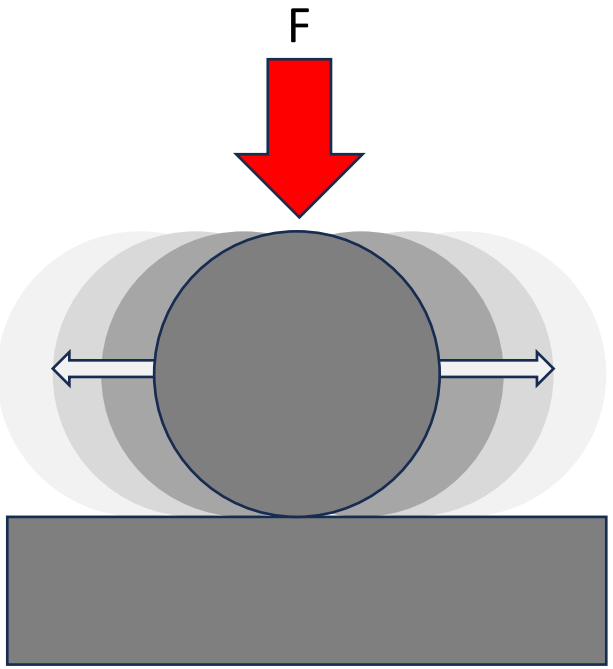


- As expected, PAO320 exhibited higher efficiency than MIN150 and MIN320.
- BO+CO+SP resulted in a lower friction than the other lubricants under these conditions (synergy).
- No measurable wear after tests → ASTM D6425.

3-. ASTM D6425

Designation: D6425 – 23

Standard Test Method for
Measuring Friction and Wear Properties of Extreme Pressure (EP) Lubricating Oils Using SRV Test Machine



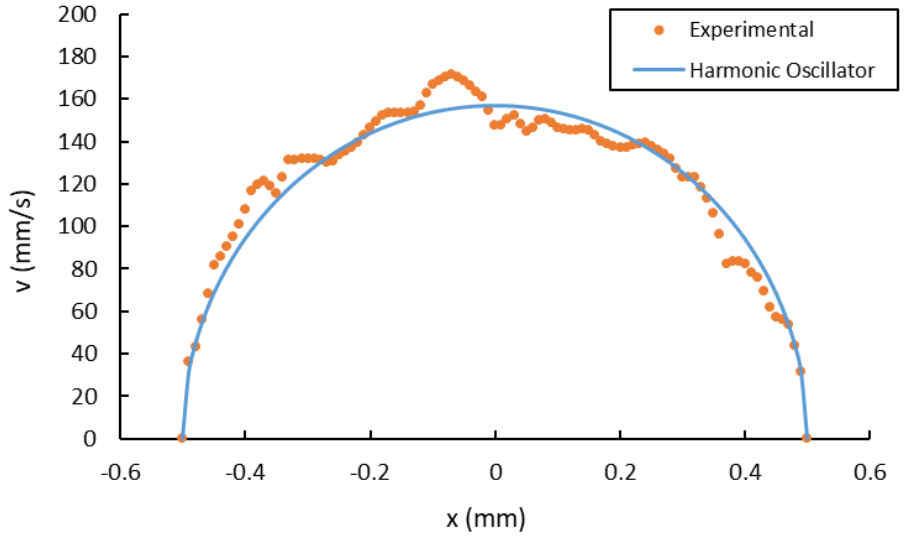
	Initial Phase	Main Phase
t (min)	0.5	120
Load (N)	50	300
Maximum Hertzian Pressure P_H (GPa)	1.7	3.1
Linear Frequency f (Hz)	50	
Stroke L (mm)	1	
Oil temperature (ºC)	80	

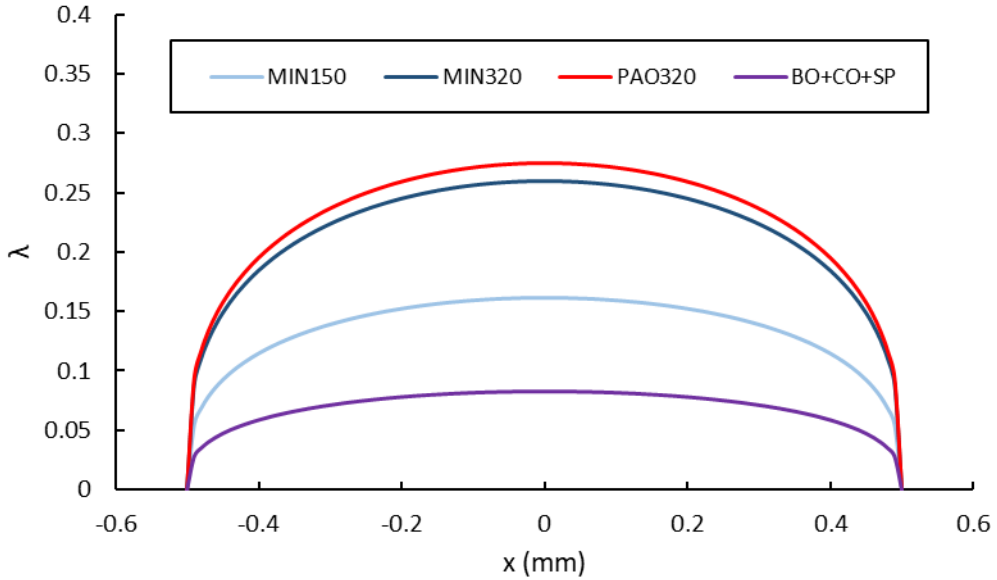
The tribological conditions were established to promote wear generation

3-. ASTM D6425: Lubrication regime

- SRVIII and SRV5 → same movement generation design.
- One of the tests was performed in SRV5, monitoring the position along the cycle (40μs HRA).
- Numerical derivative of position with respect to time:

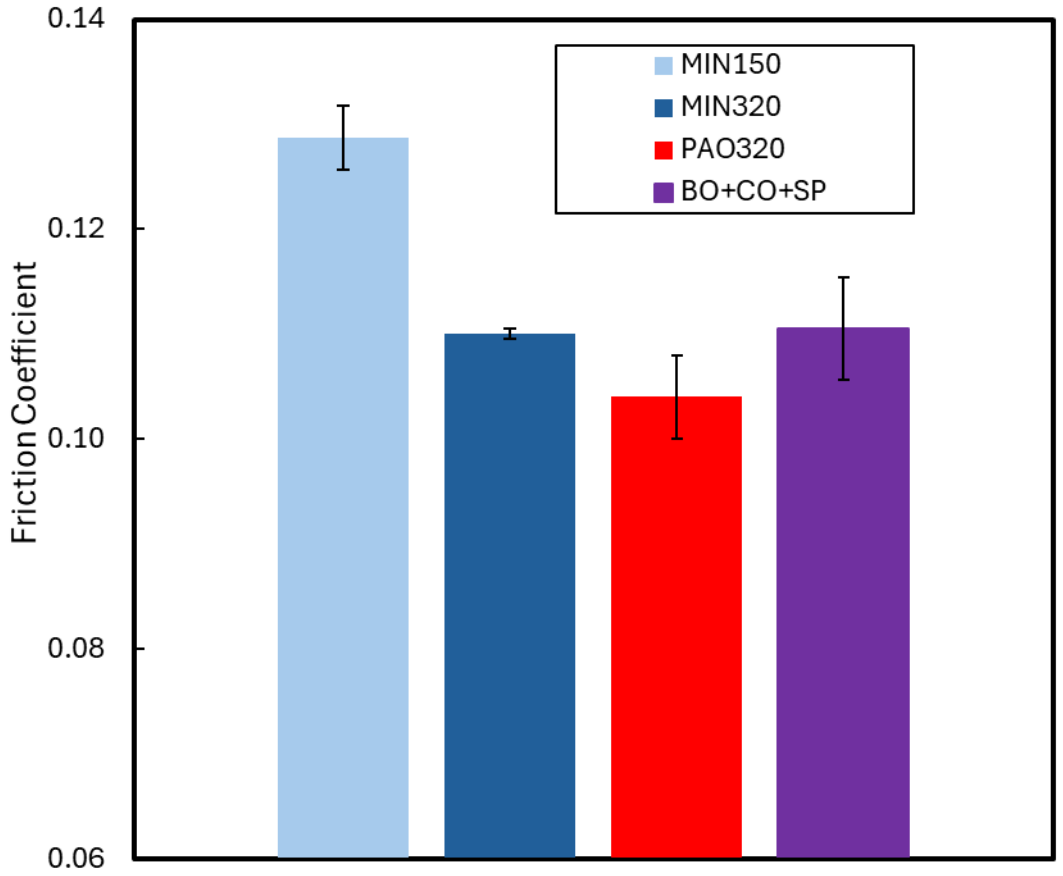
$$v = \frac{dx}{dt}$$



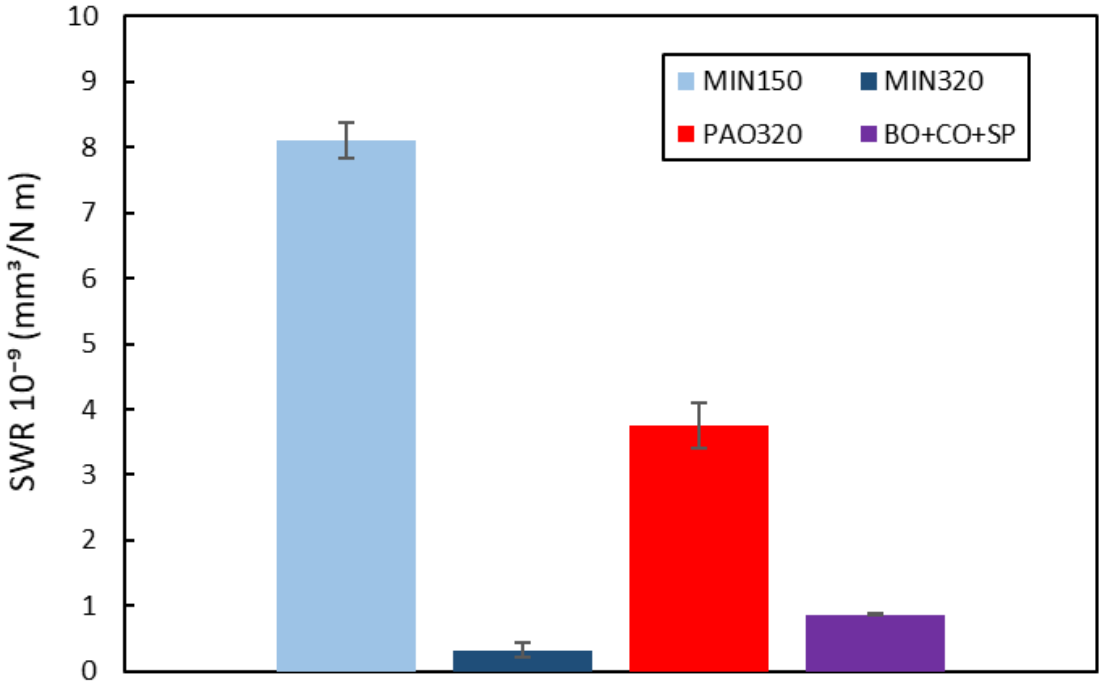


3-. ASTM D6425: friction

- MIN150 presented higher friction than the rest of the lubricants.
- Considering overlapping of the error bars, minor differences between MIN320, PAO320 and BO+CO+SP.
- Different trends from that observed in the traction curves.



3-. ASTM D6425: wear



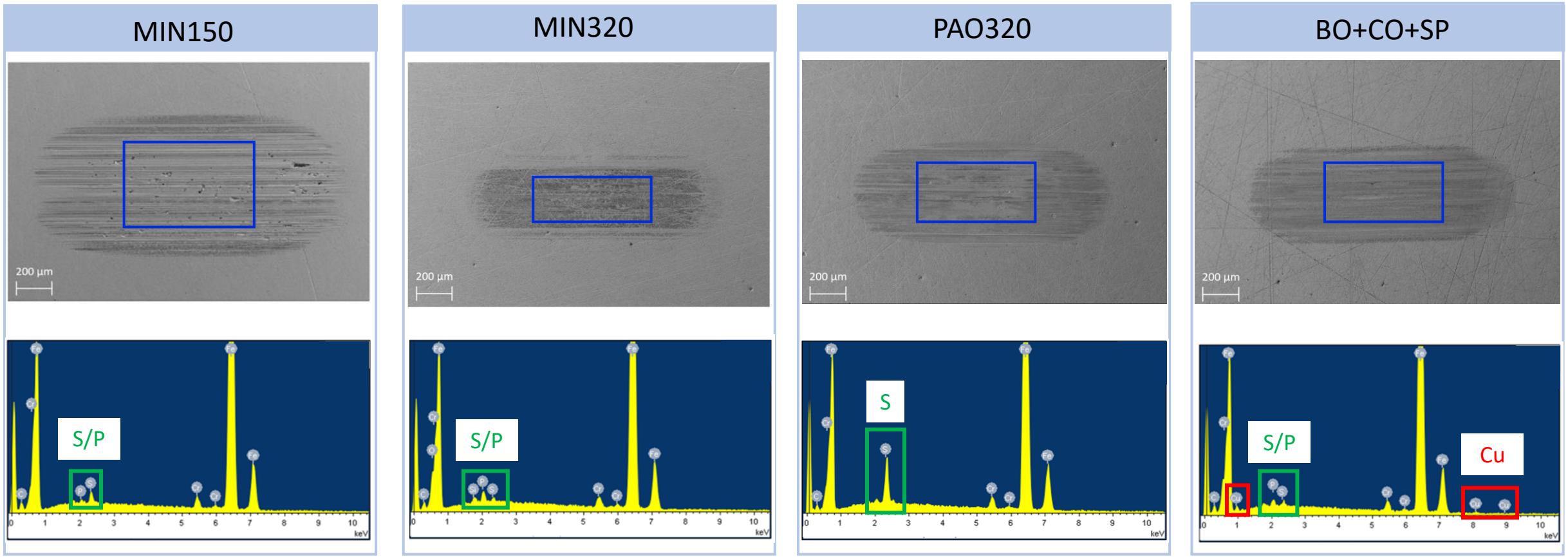
After measuring wear volume on disc, SWR was calculated:

$$SWR = \frac{V}{W\ D}$$

The synergy between CO and SP showed a wear reduction of 89% and 77% compared to MIN150 and PAO320, respectively.

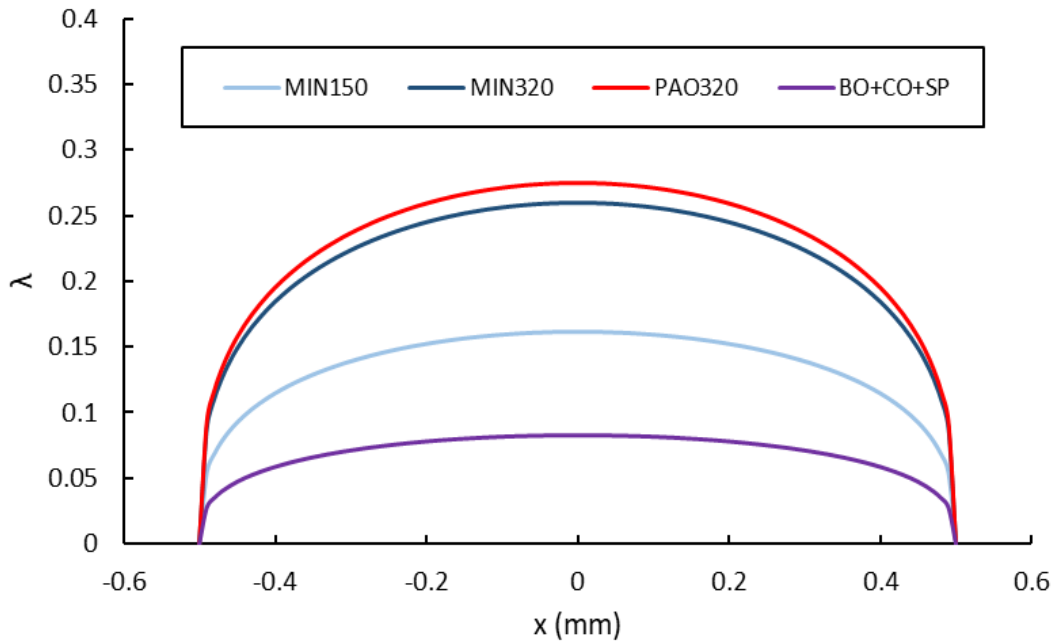
However, MIN320 exhibited a better performance than BO+CO+SP

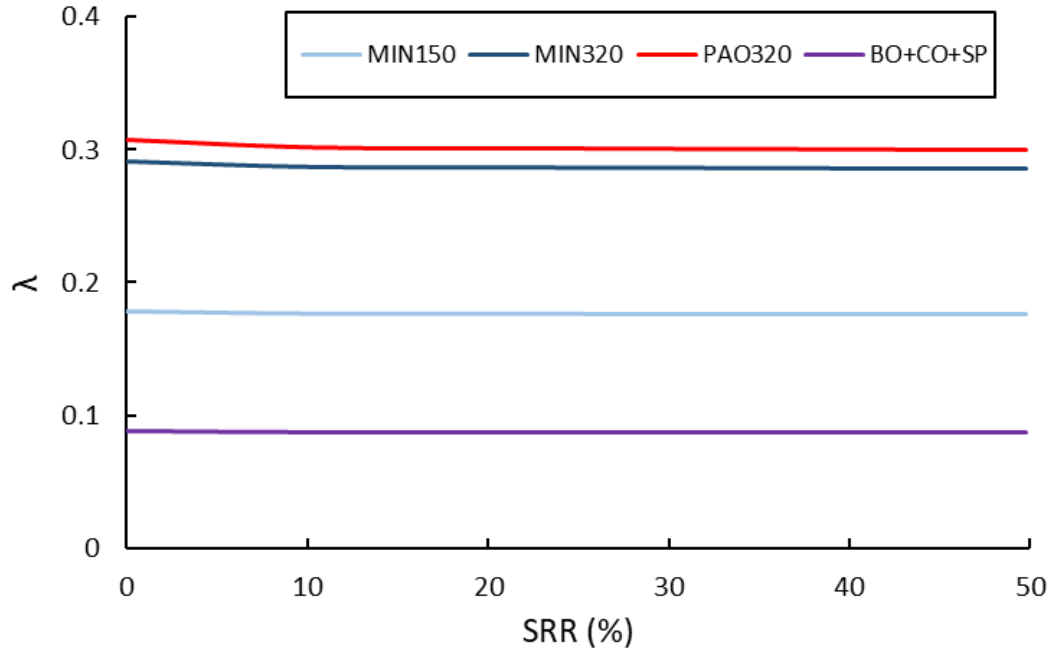
3-. ASTM D6425: Surface analysis and EDS



All commercial oils contained S and P in the wear scars, evidencing the reaction of their respective EP additives. In the case of BO+CO+SP, S and P are again detected along with Cu, confirming the synergistic effect.

3-. Comparison of λ between traction curves and ASTM D6425 conditions





Difference: Contact temperature ↔ Additive reactivity

4-. Conclusions and future work

1. The synergy observed between CO and the SP additive package in an ISO VG 46 oil shows improved wear performance compared to higher-viscosity commercial lubricants.
2. In a rolling–sliding contact more representative of those found in bearings and gears, BO+CO+SP is the most efficient lubricant under boundary lubrication conditions.
3. In terms of friction, the trends observed between ASTM D6425 and the traction curves differ. It is therefore necessary to understand the underlying reasons for these discrepancies.

Tekniker
Parke Teknologikoa
C/ Iñaki Goenaga, 5
20600 Eibar (Gipuzkoa)
Tel: +34 943 20 67 44
www.tekniker.es