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The compatibility of multilayer surface treatments with bio-lubricants base oils

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- Introduction
- Test Materials and Method
- Results
- Lubricant Interactions
- Further Work

Introduction

Drivers for using more environmentally acceptable lubricants;

- For industry – legislative environment
- Downstream user demand

Largest markets are currently EU and USA

Emerging markets, such as India, Brazil and China are predicted to grow faster due to the increase in passenger car use and the availability of crops to produce bio-lubricants.

Grand View Research. *Bio-lubricants Market Analysis By Raw Material, By Application, Industrial, by end-use, Segment Forecasts To 2024.* 2016.

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Applications

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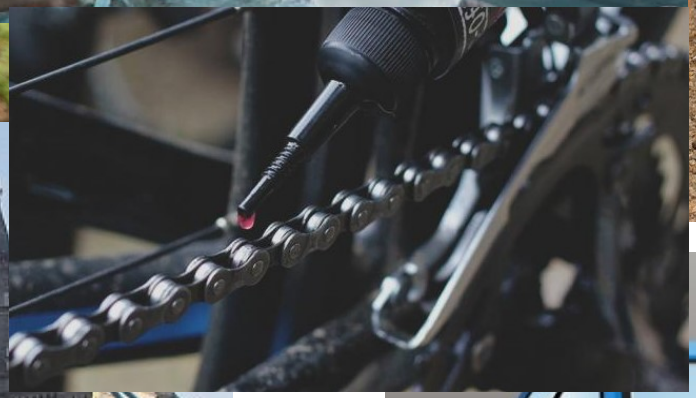

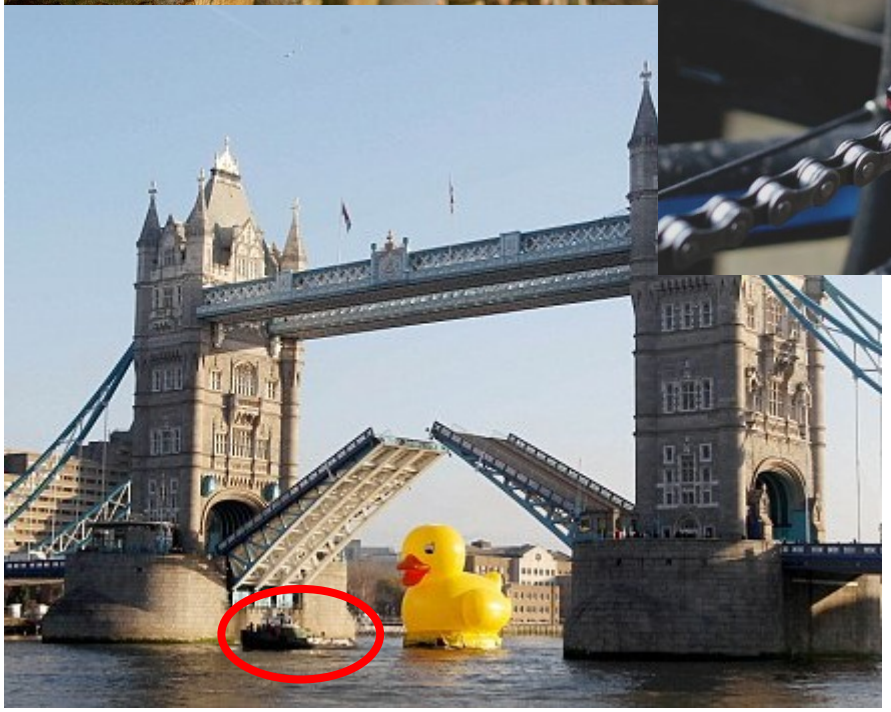

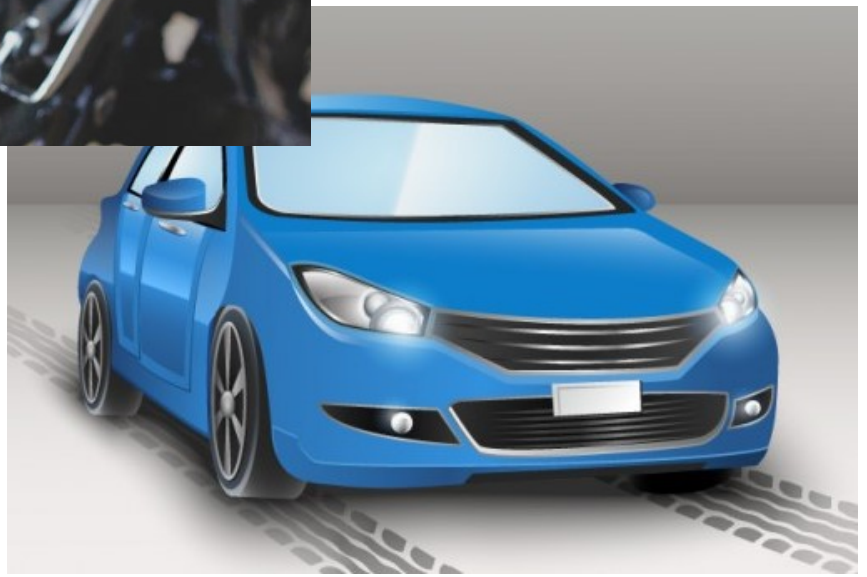

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Test Materials and Method

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Base Oils

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- **Soybean Oil –** Triglyceride Structure
- **Jojoba Oil –** wax, long chain monohydric alcohol and carboxylic acid
- **Mineral base oil –** Paraffinic group 1 base stock

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Surface Treatments

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- **EN09 steel substrates -** surface ground or super finished
- **DLC,** commercial Dymon-iC™
- **Shot Blasting,** proprietary two stage process - spherical ceramic media and solid lubrication media, tin and Molybdenum Disulphide
- **Calcium sulphate based chemical dip,** Proprietary treatment using calcium sulphate

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Surface Treatments

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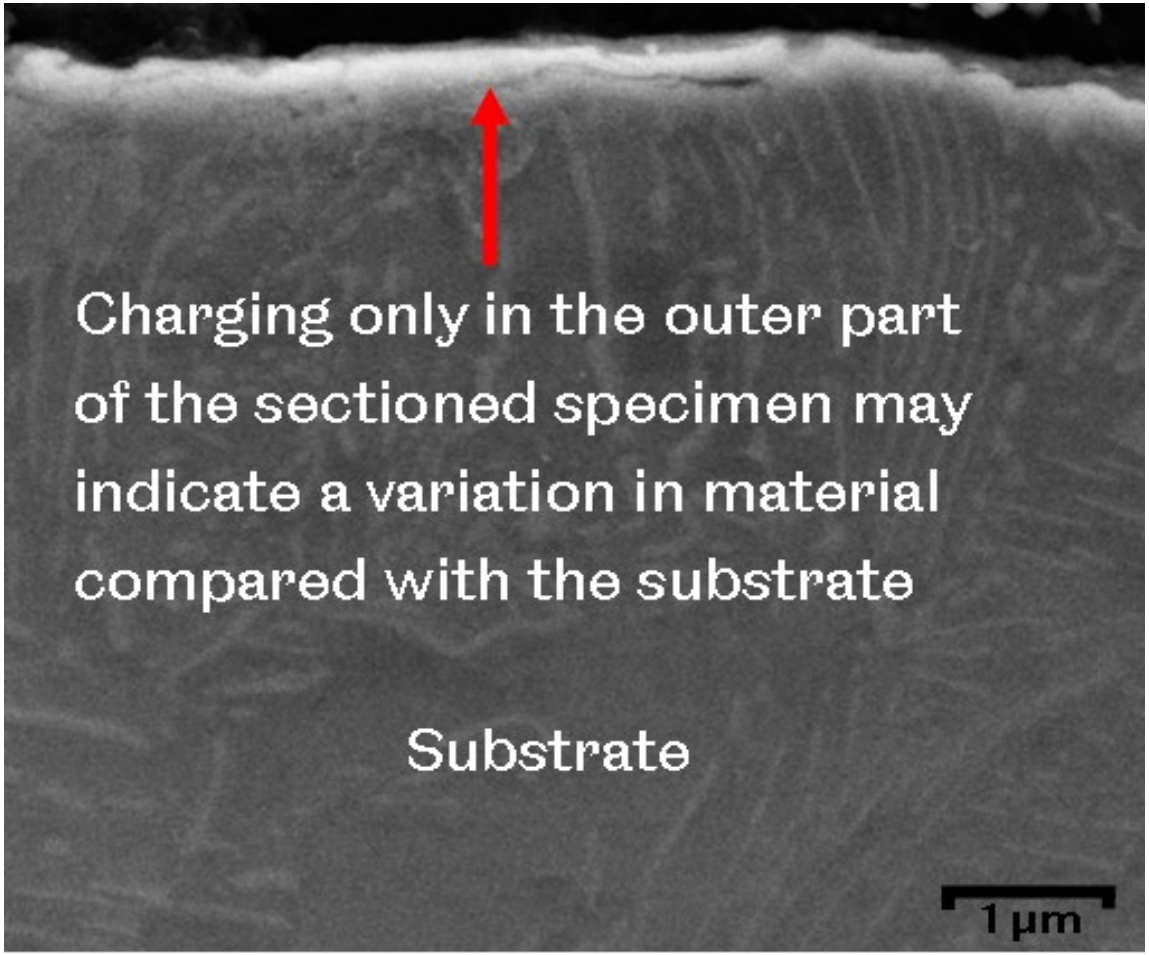

Surface Treatment Combinations

- DLC followed by chemical dip
- Chemical dip followed by DLC
- Shot blasting followed by DLC
- Shot blasting followed by Chemical dip
- Shot blasting, chemical dip, DLC

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Surface Treatment Combinations

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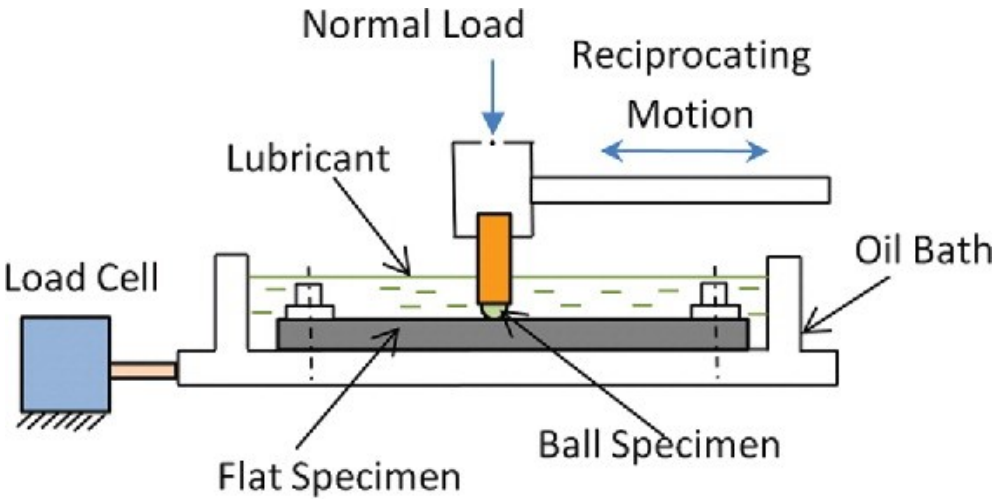
	Super finished	DLC	Shot Blasting	Chemical dip
1		A		
2	A	B		
3			A	
4	A		B	
5	A	B		C
6	A			B
7		A		B
8	A		B	C
9				A
10			A	B
13	A	C		B
14		B		A
15		C	A	B
16		B	A	
17	A	C	B	

Test Method

Experimental Parameters	Value
Speed, rpm	260
Temperature, ˚C	100
Stroke, mm	15
Normal load, N	40
Chrome steel ball bearing, Surface roughness, µm	0.038
Ball Hardness, Hv	800
Volume of oil used, ml	30
Test duration, min	60



A. Bahari, T. Slatter and R. Lewis, "Friction and Wear Phenomena of Vegetable Oil–Based Lubricants with Additives at Severe Sliding Wear Conditions," *Tribology Transactions* , 2016.

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Results

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Wear

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Rank	Soybean	Volume loss, mm^3	Jojoba	Volume loss, mm^3	Mineral	Volume loss, mm^3
1	SF Steel	0.003	SF chemical Dip	0.005	SF Steel	0.005
2	SF DLC, Chemical Dip	0.004	SF, Shot Blasting	0.005	SF Chemical Dip	0.007
3	SG, Shot Blasting, DLC	0.007	SF Steel	0.005	SG, Chemical Dip, DLC	0.008
4	SF, Chemical Dip, DLC	0.007	SF, Shot Blasting, Chemical Dip	0.007	SF, Shot Blasting	0.008
5	SF, DLC	0.008	SG, Shot Blasting, DLC	0.007	SF DLC, Chemical Dip	0.008

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Friction

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Rank	Soybean	Coefficient of Friction	Jojoba	Coefficient of Friction	Mineral	Coefficient of Friction
1	SF Steel	0.06	SF chemical Dip	0.07	SF Steel*	0.05
2	SF DLC, Chemical Dip	0.07	SF, Shot Blasting	0.07	SF Chemical Dip	0.09
3	SG, Shot Blasting, DLC	0.07	SF Steel	0.07	SG, Chemical Dip, DLC	0.12
4	SG, Chemical Dip, DLC	0.09	SF, Shot Blasting, Chemical Dip	0.06	SF, Shot Blasting	0.11
5	SF, DLC	0.07	SG, Shot Blasting, DLC	0.07	SF DLC, Chemical Dip	0.1

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Wear – Steel

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Soybean Oil

Jojoba Oil

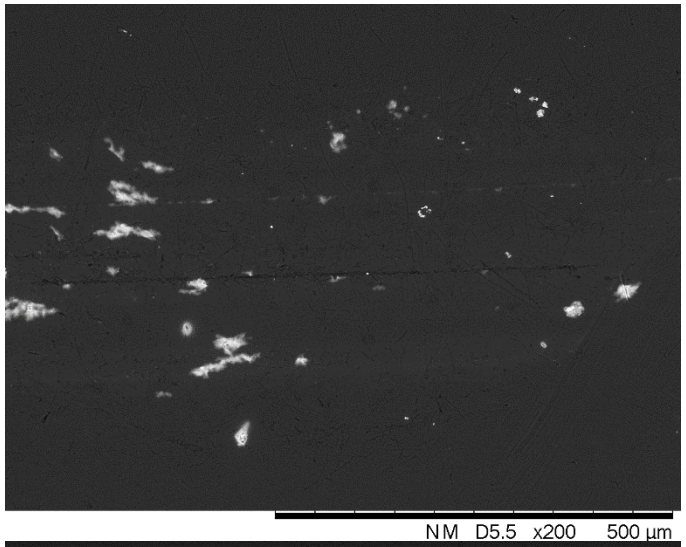
Mineral Oil

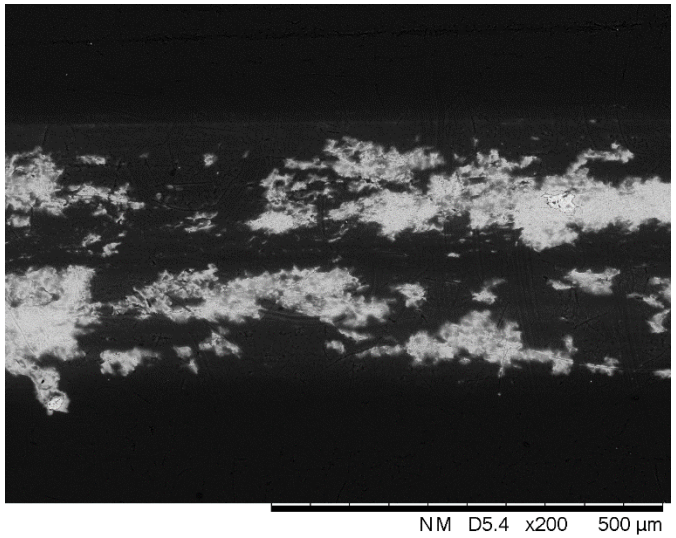
Wear – DLC containing coatings

Soybean Oil

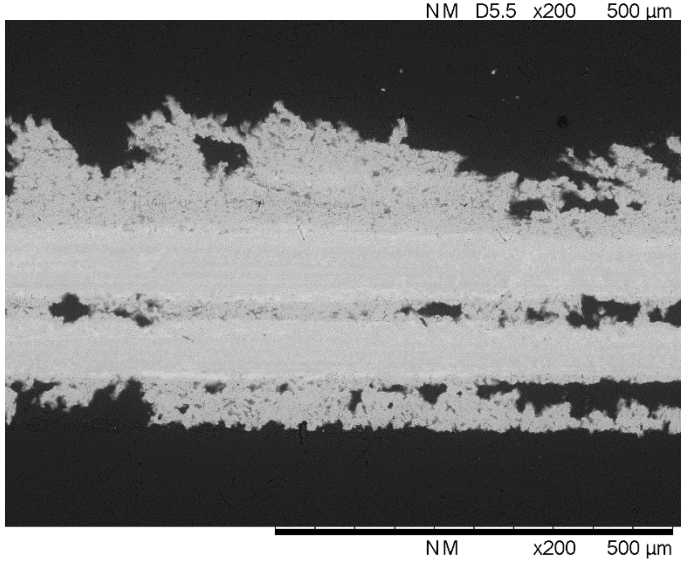
Mineral Oil

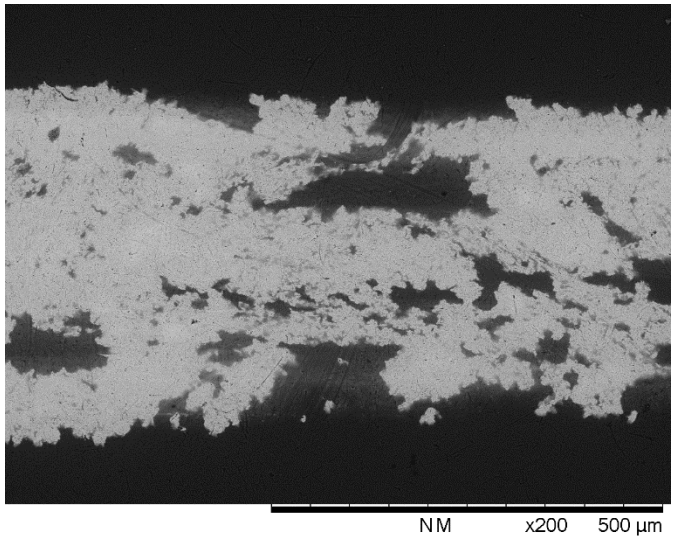
Super finished DLC, chemical dip





Super finished, DLC



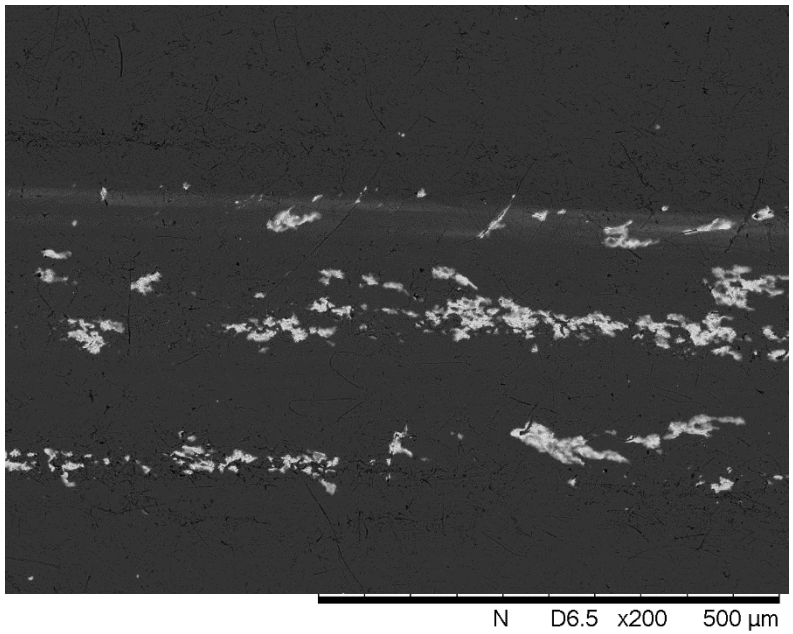


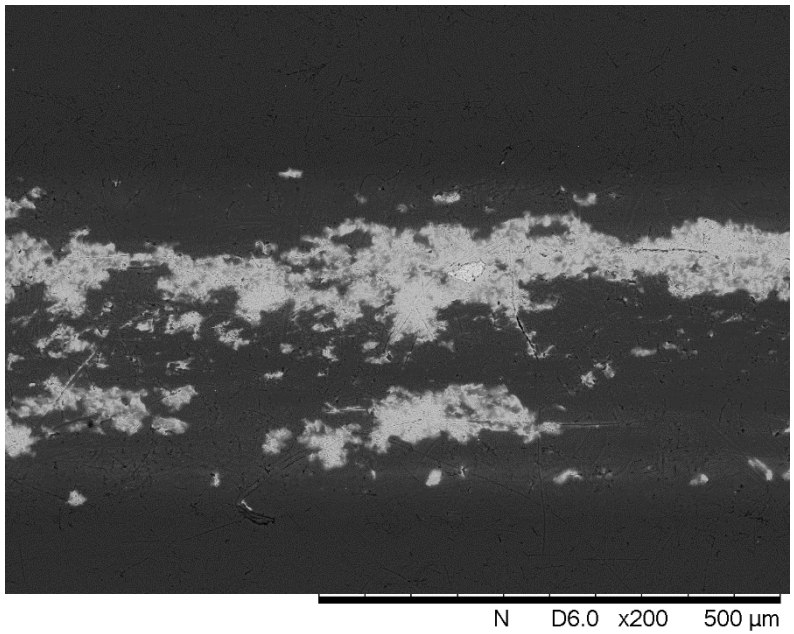
Wear – DLC containing coatings

Soybean Oil

Mineral Oil

Super finished, chemical dip, DLC



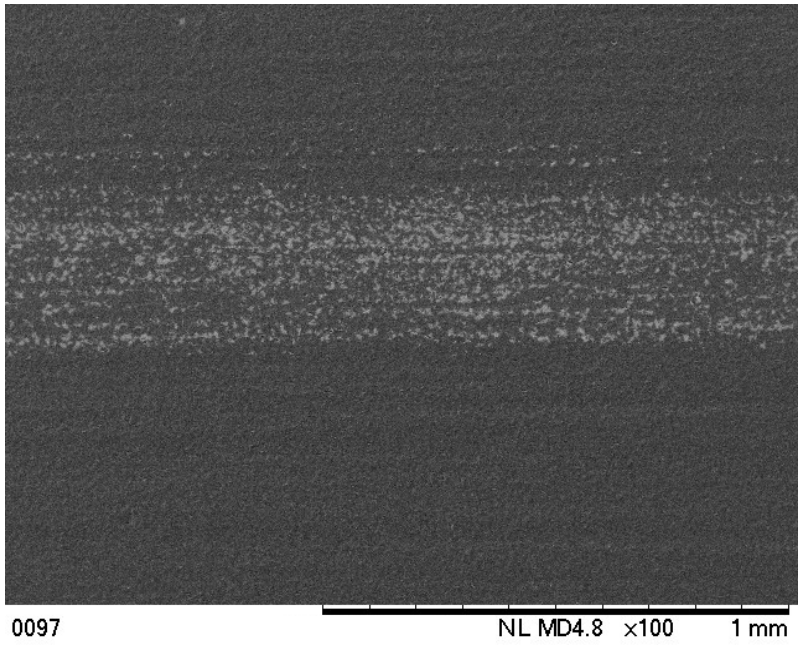


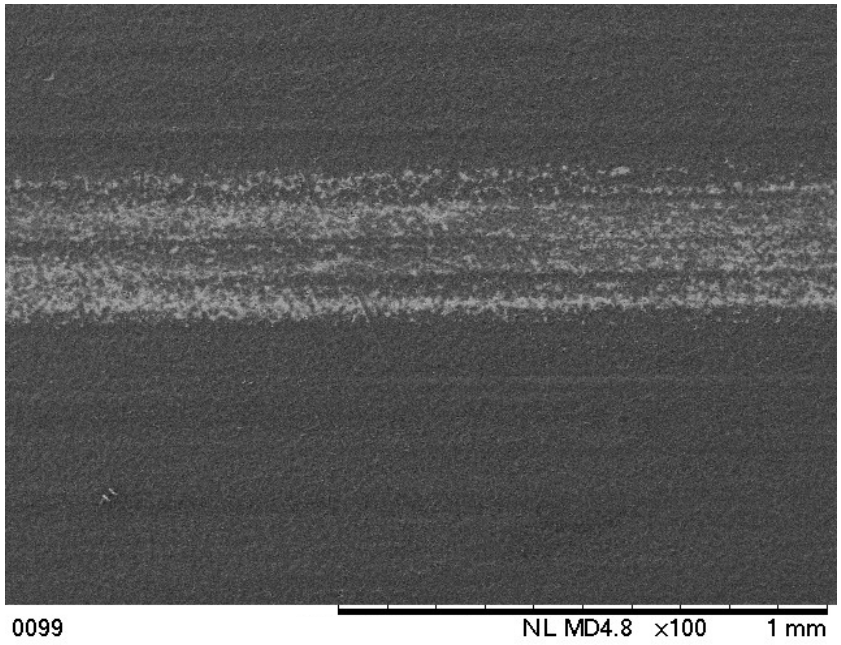
Wear – DLC containing coatings

Soybean Oil

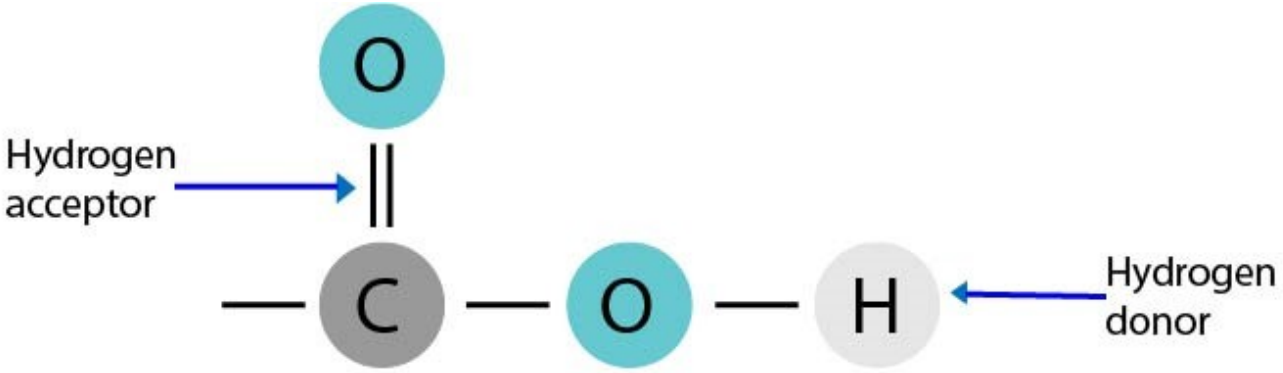
Mineral Oil

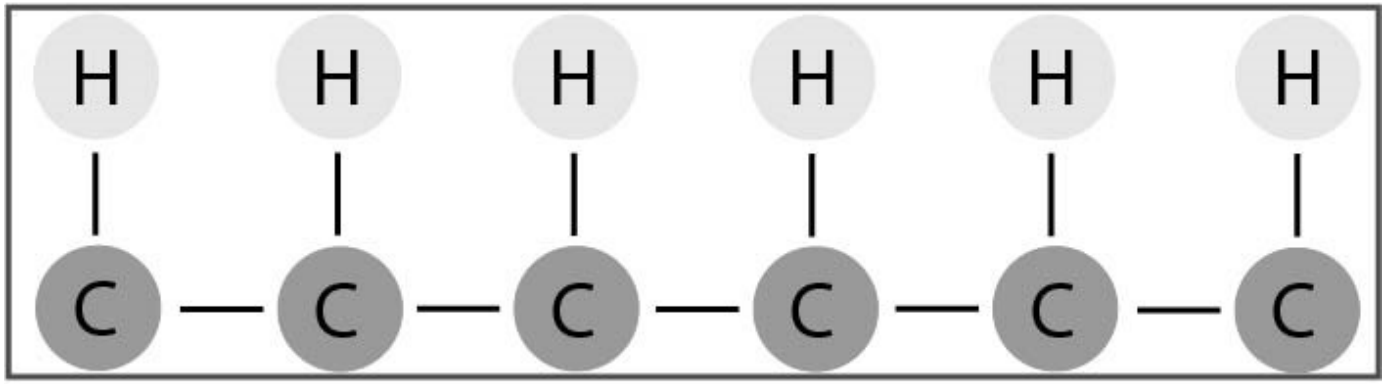
Surface ground, Shot blast, DLC





Wear – DLC containing coatings

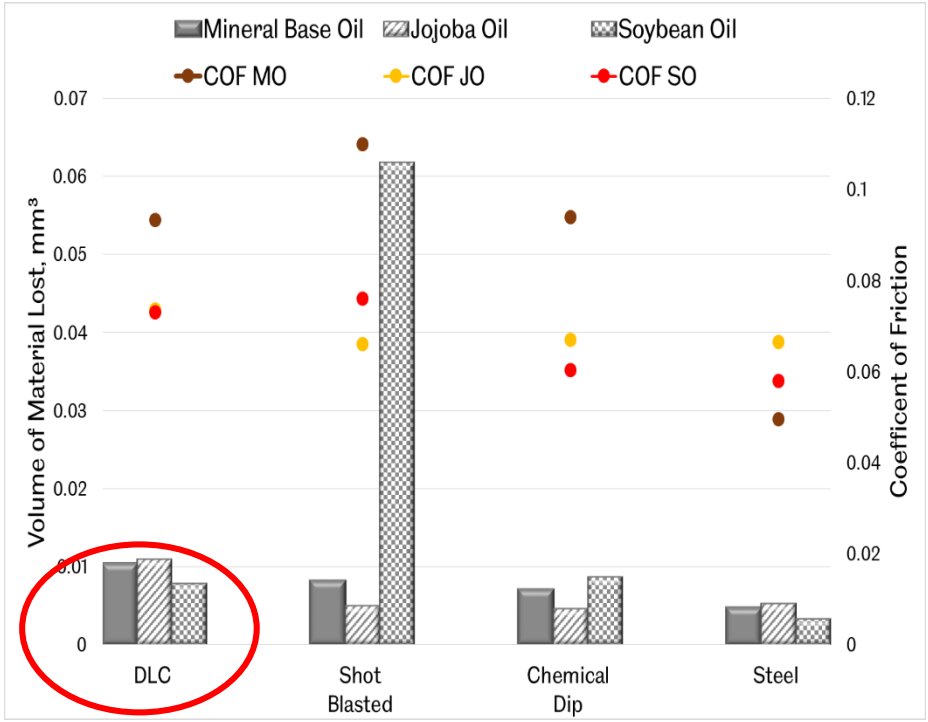




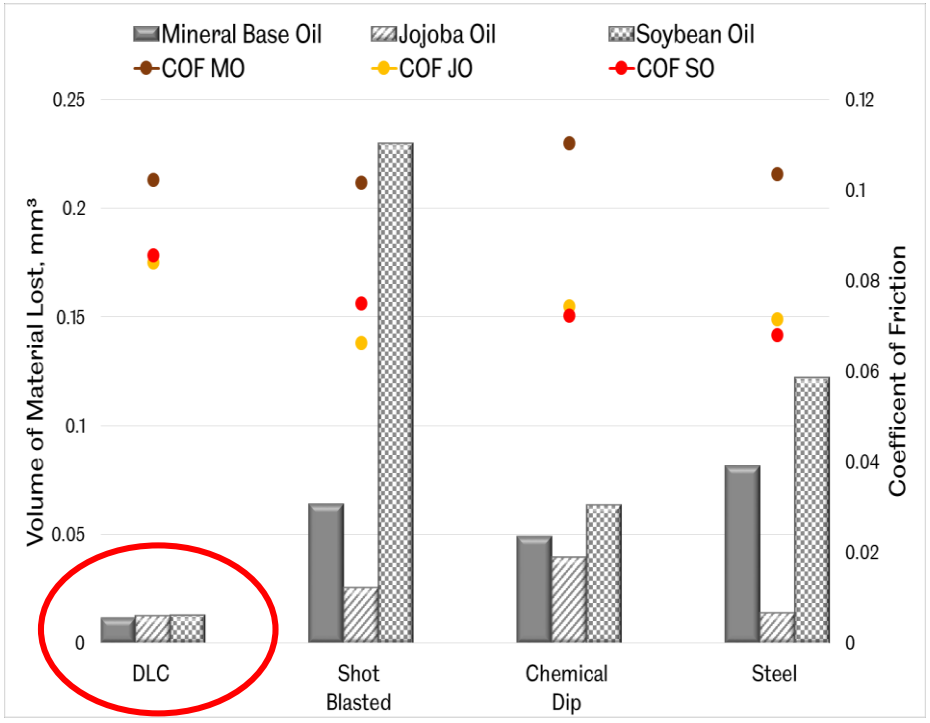
DLC - fatty acid interaction

Surface Finish

Super Finished Substrate



Surface Ground Substrate



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Surface Finish

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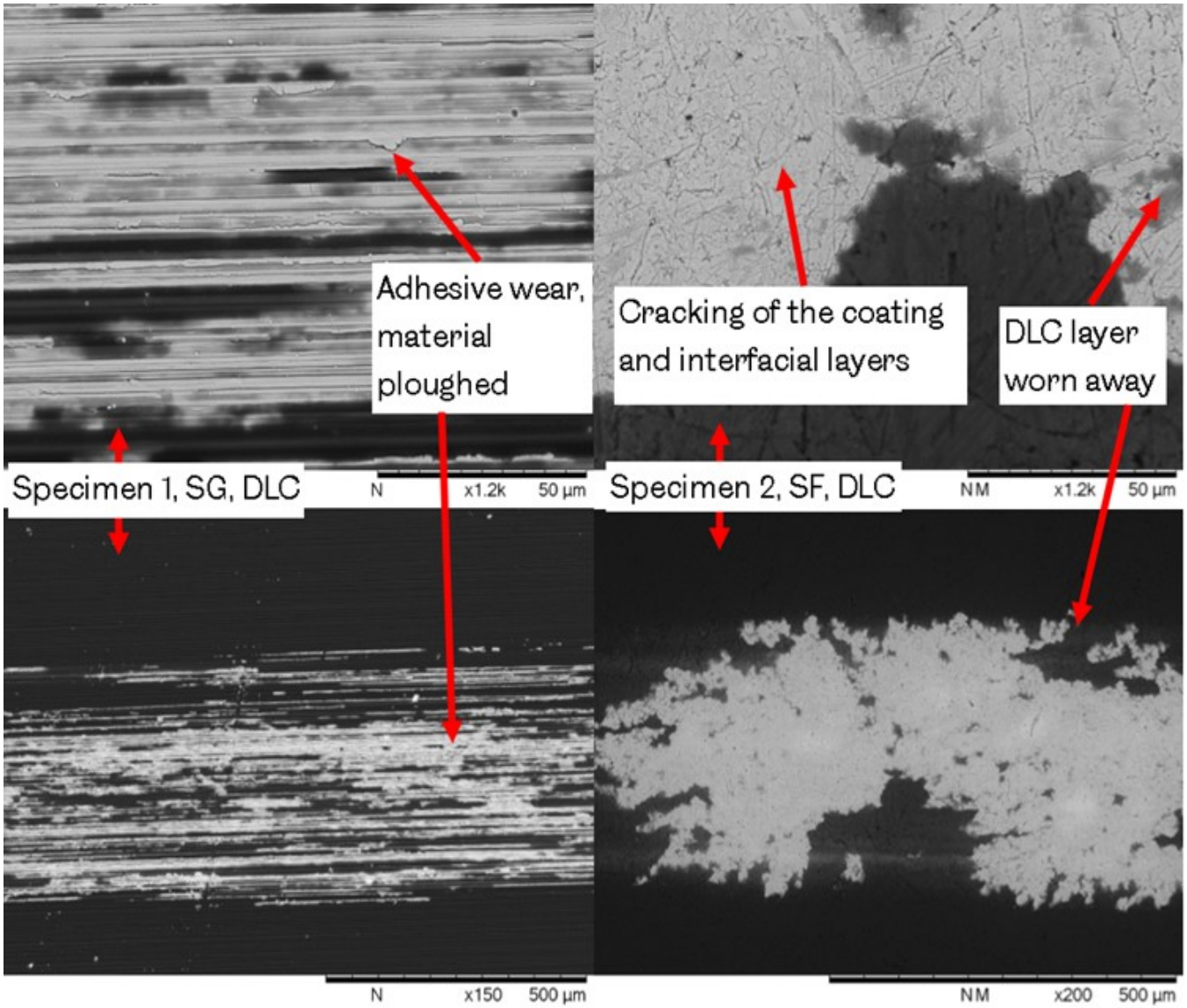
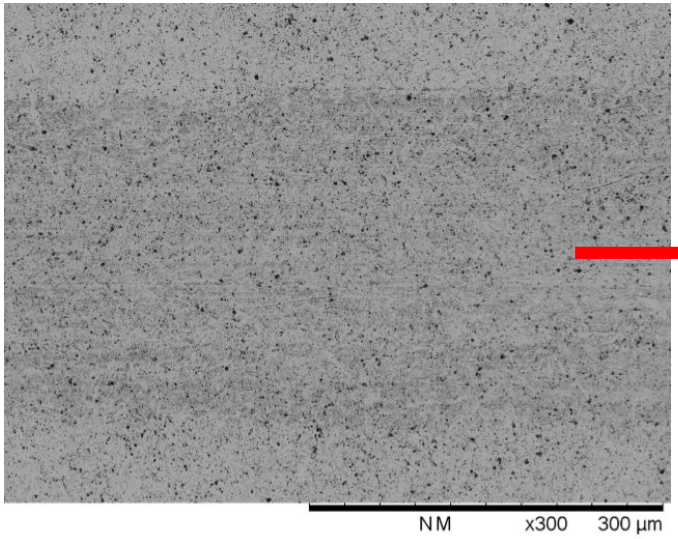
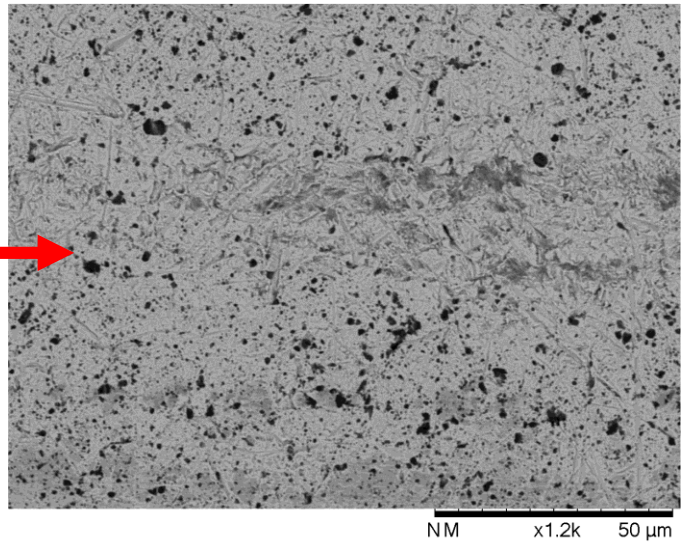


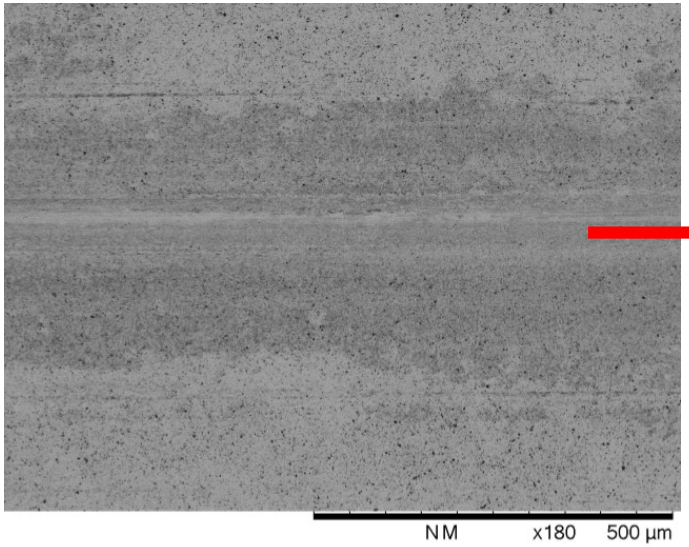
Wear – Calcium sulphate containing coatings

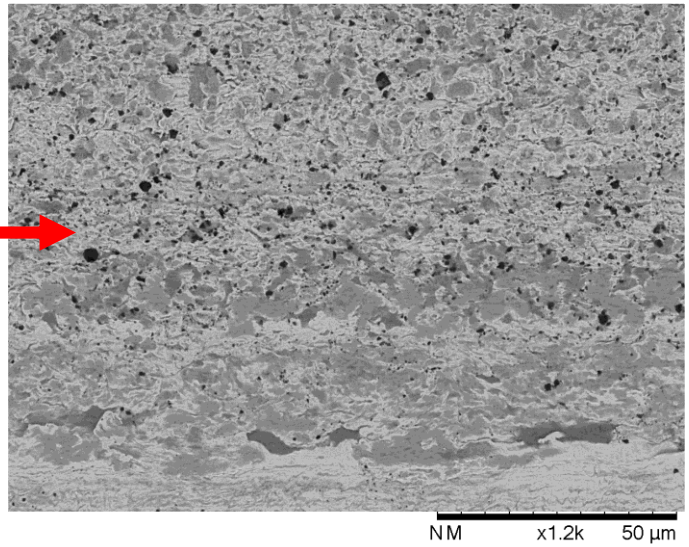
Jojoba Oil



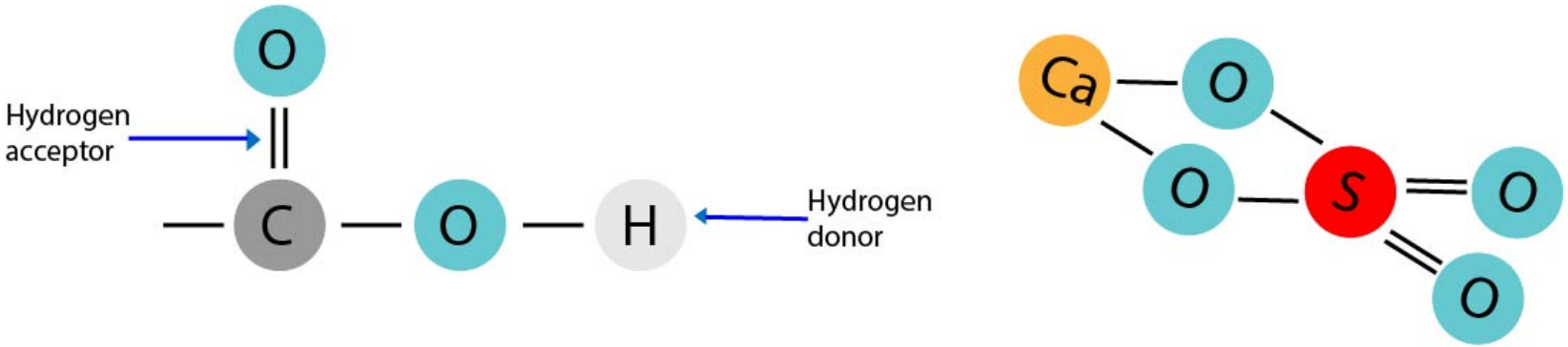


Mineral Oil





Wear – Calcium sulphate containing coatings



Calcium Sulphate - fatty acid interaction

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Lubrication Interactions

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Summary of Interactions

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- **Steel** - dominated by chemisorbed films formed by the carboxylic acid groups - very effective wear and friction reduction mechanism for smooth surfaces

- **DLC coatings** - dominated by physi- and chemisorbed films formed between the dangling bond orbitals on the DLC surface and the carboxylic acid groups.

- **Calcium based chemical dip - c**alcium bonds with the fatty acids to enhance lubricity. Sulphur forms bonds with the steel surface. Physisorbed films are generated between aluminium oxide and fatty acids.

- **Shot blasting -** carboxylic acid group acts as an oxidant and bonds with Mo or S to form a physisorbed film.

Summary

- Bio base stocks can reduce wear and friction compared with mineral oils
- Soybean oil is most effective and economically choice
- Some benefit to layering a chemical dip or shot blasting before applying DLC
- Most benefit to adding a layer over DLC – sacrificial layer?

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Further Work

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Further Work

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- Prove (or disprove) the lubricant and surface interactions through assessment of tribofilms
- Explore methods for simplifying interaction of bio-lubricants and surfaces using surface energy and tension data
- Formulated bio-lubricant tests with EAL style additives

With Thanks

Dr T. Slatter and Prof. R. Lewis –The Leonardo Tribology Centre, The University of Sheffield, UK

Dr U. Little – South West College, UK

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