Trends in Coatings and Nanomaterials in Lubricant Industry to enhance Fuel Economy and Minimize Wear in Internal Combustion Engines

KAUSTAV SINHA
Currently with Infineum USA L.P., Linden, New Jersey USA
kaustav.sinha@infineum.com

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Coatings in Lubricant Industry

(will discuss in depth the use of diamond-like carbon materials in engines for improving fuel economy and wear)

Friction, Wear, and Surface Film Formation Characteristics of Diamond-Like Carbon Thin Coating in Valvetrain Application

Tribology Transactions, 54: 1, 104 — 114, 2010.

KAUSTAV SINHA[#] (presenter)

[#] (work done at Ford) Currently with Infineum USA L.P., Linden, New Jersey USA

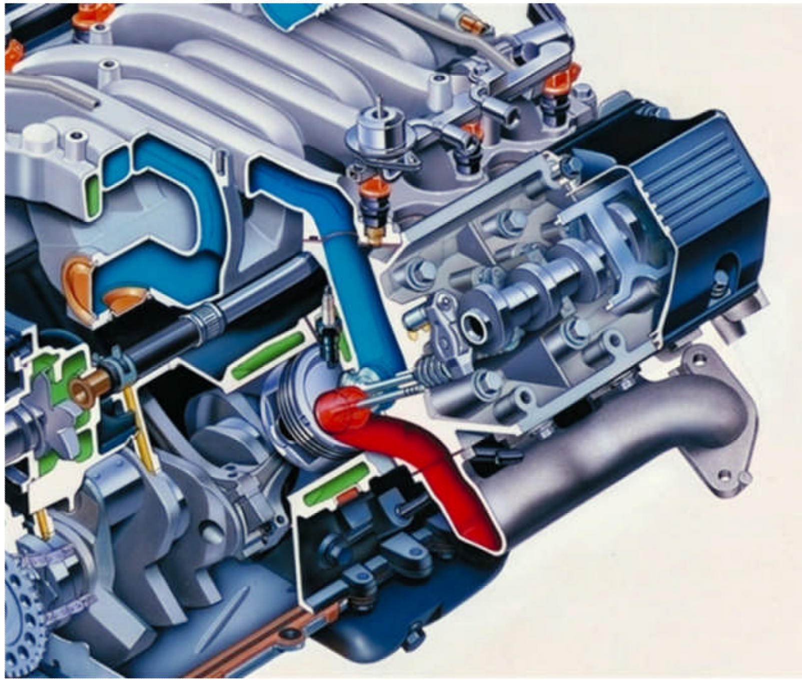
kaustav.sinha@infineum.com

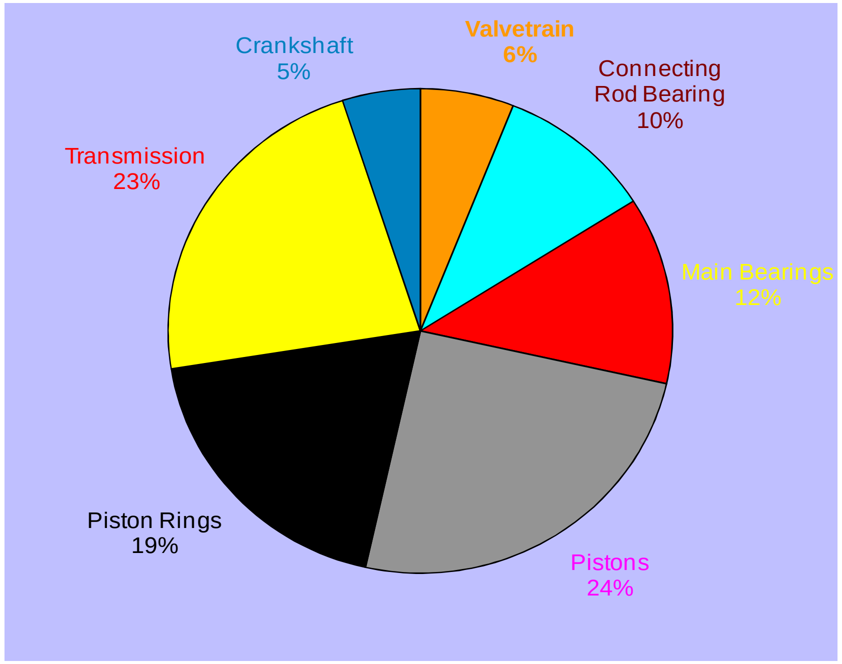
Co-authors: Arup Gangopadhyay; Dairene Uy; Douglas G. Mcwatt; Robert J. Zdrodowski; Steven J. Simko

Ford Motor Company, Dearborn, Michigan USA

Introduction

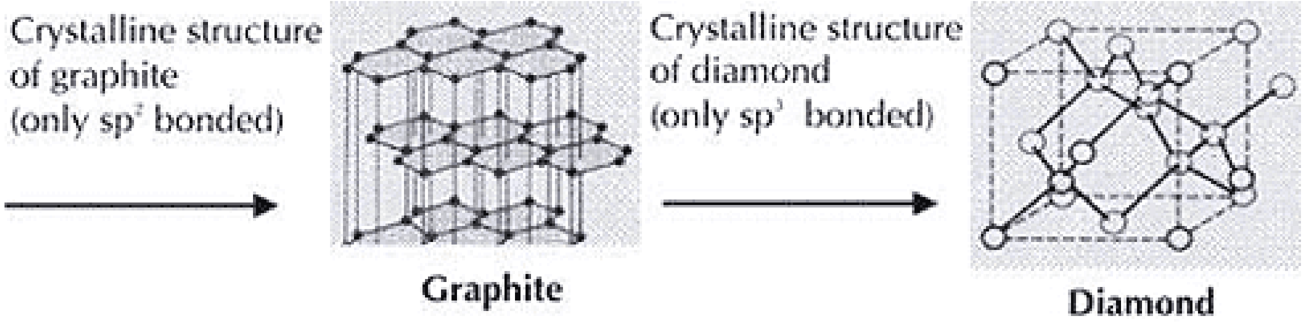
Frictional losses in vehicles

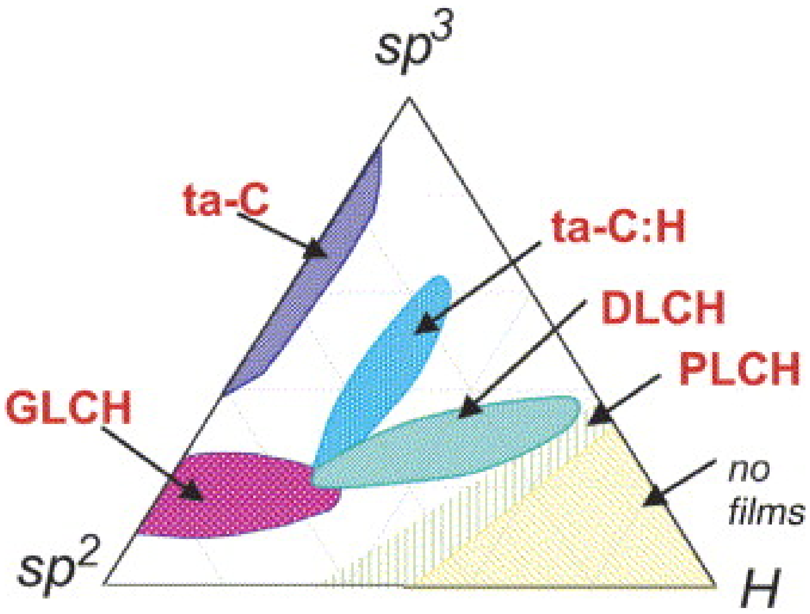


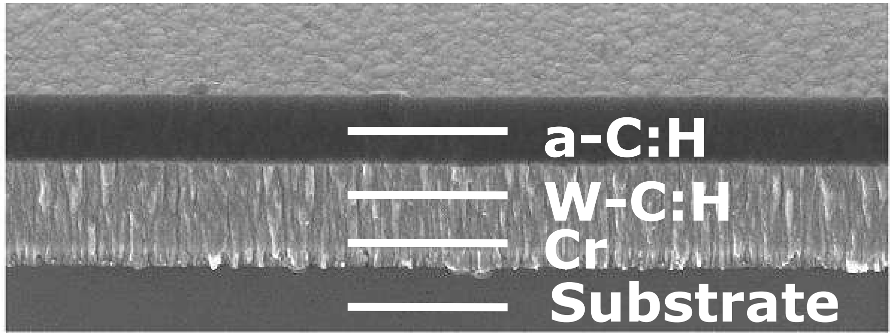


Ref: Benchaita, M.T., and Lockwood, F.E., Lub. Sci., July, (5), p261, 1995

Diamond Like Carbon (DLC) Coatings







- **Hardness (30-80 GPa)**
- **Friction coefficient < 0.1**

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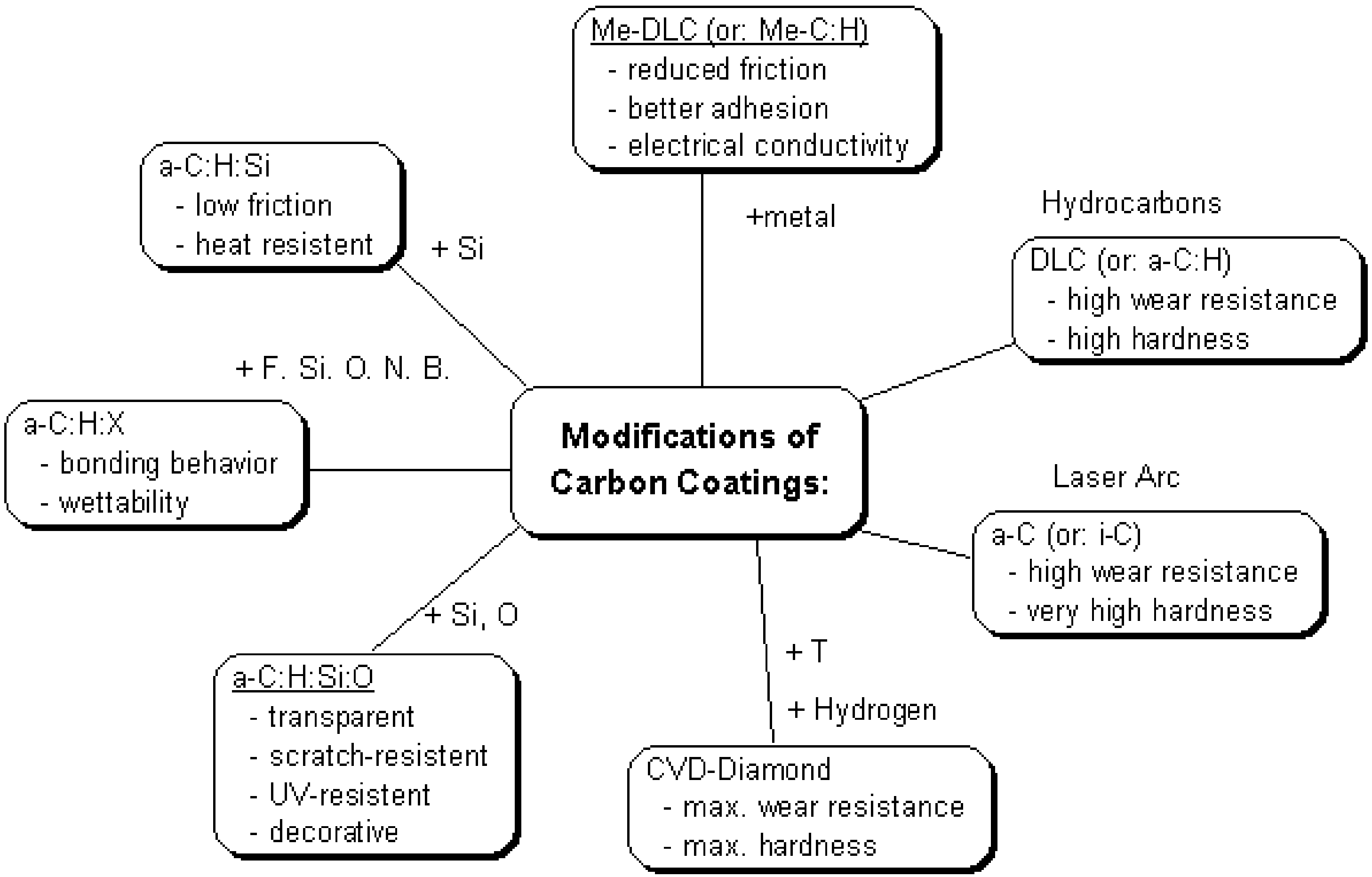
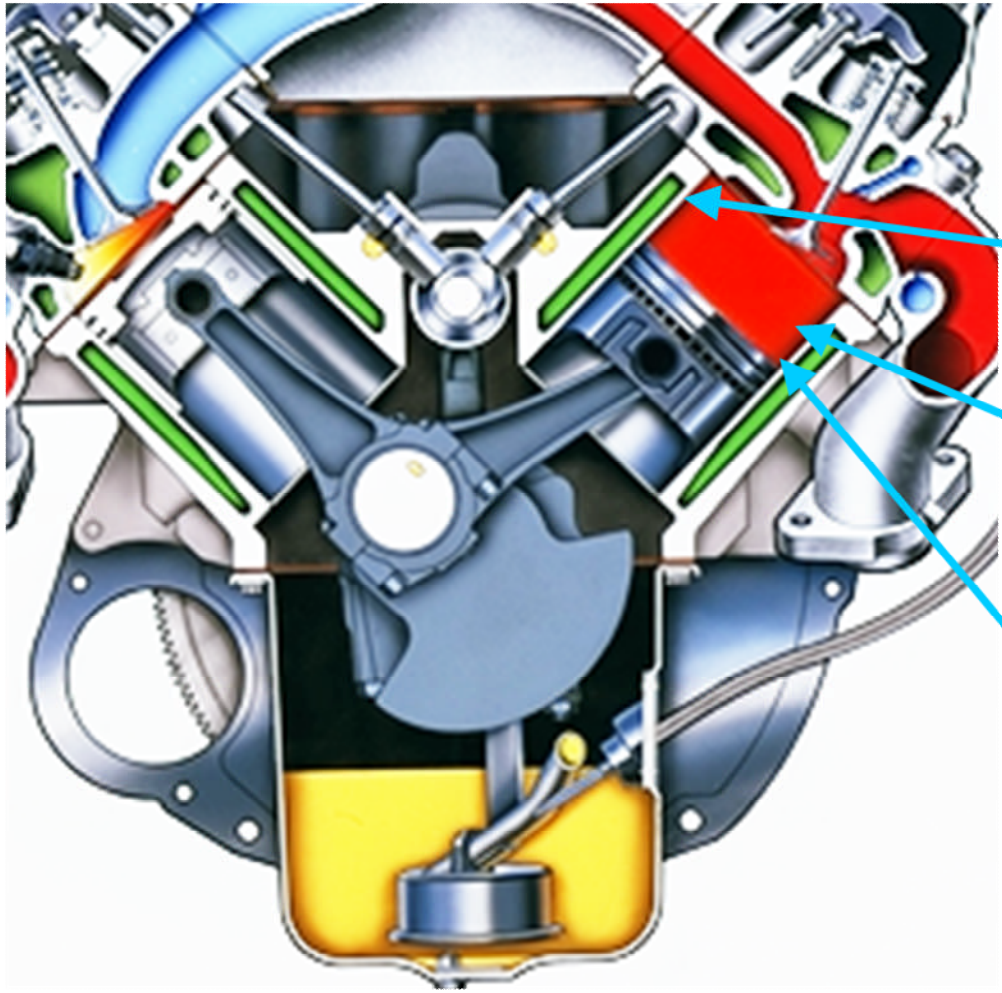
Cinzia Casiraghi, John Robertson and Andrea C. Ferrari, “Diamond-like carbon for data and beer storage” Materials Today, Volume 10, Issues 1-2, January-February 2007, Pages 44-53

DLC Coatings



Engine Applications



Friction Reduction

Low friction coating

Surface texture control

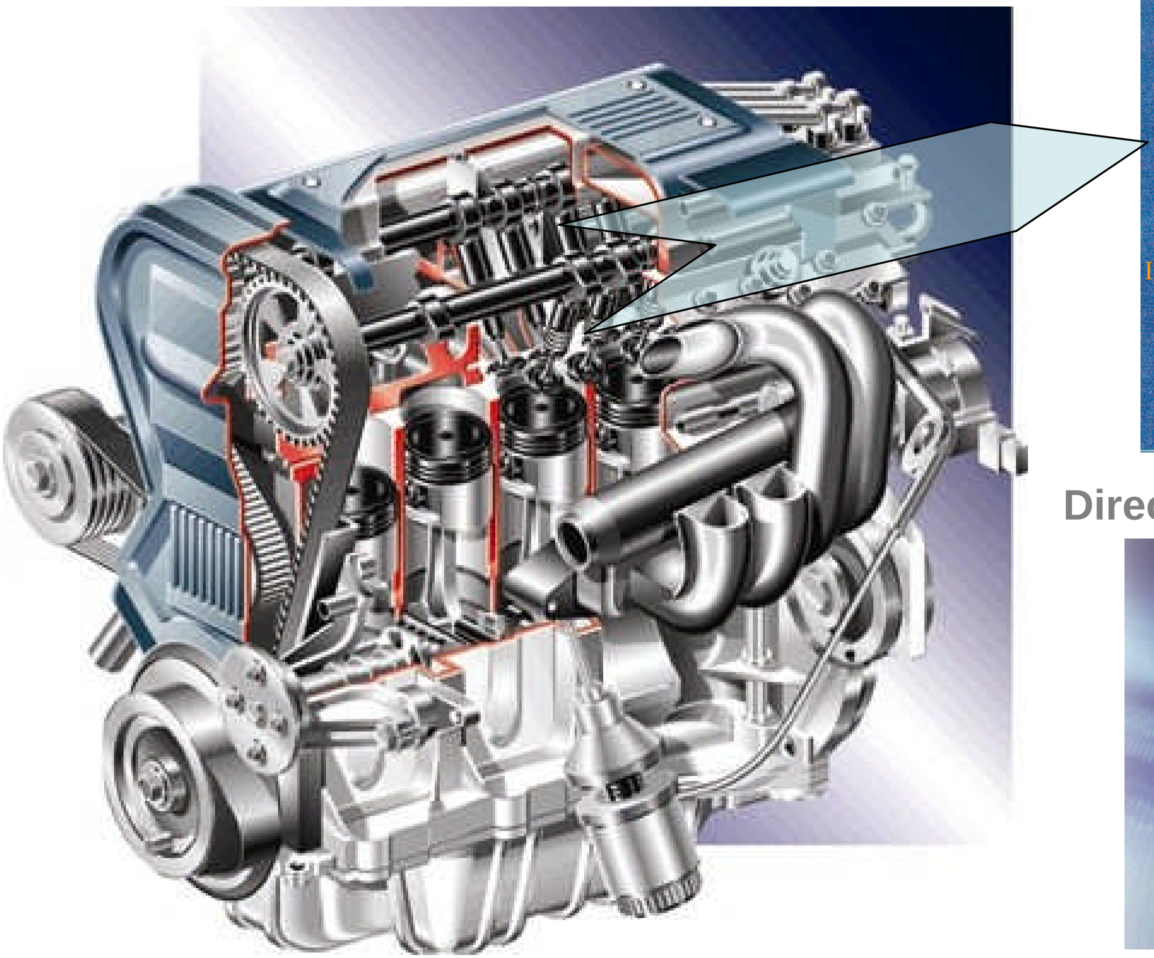
Durability

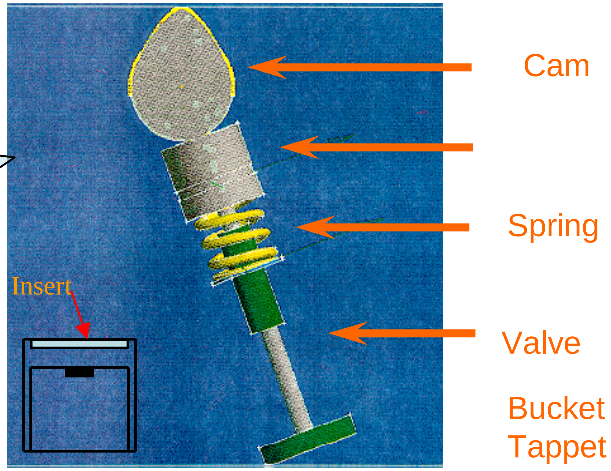
Wear resistant coating for aluminum bores

Environment

Need better material and /or finish for reduced oil consumption

Engine Applications





Direct Acting Bucket Tappet

Diamond like carbon (DLC) coating on the bucket tappet to reduce friction and enhance fuel efficiency

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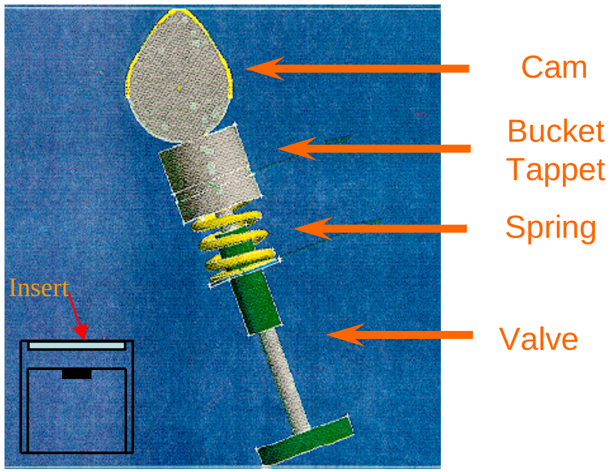
Objectives

- To understand the friction and wear reduction potential under boundary and mixed lubrication regimes.
- To understand the interactions of lubricant additives with DLC coating.

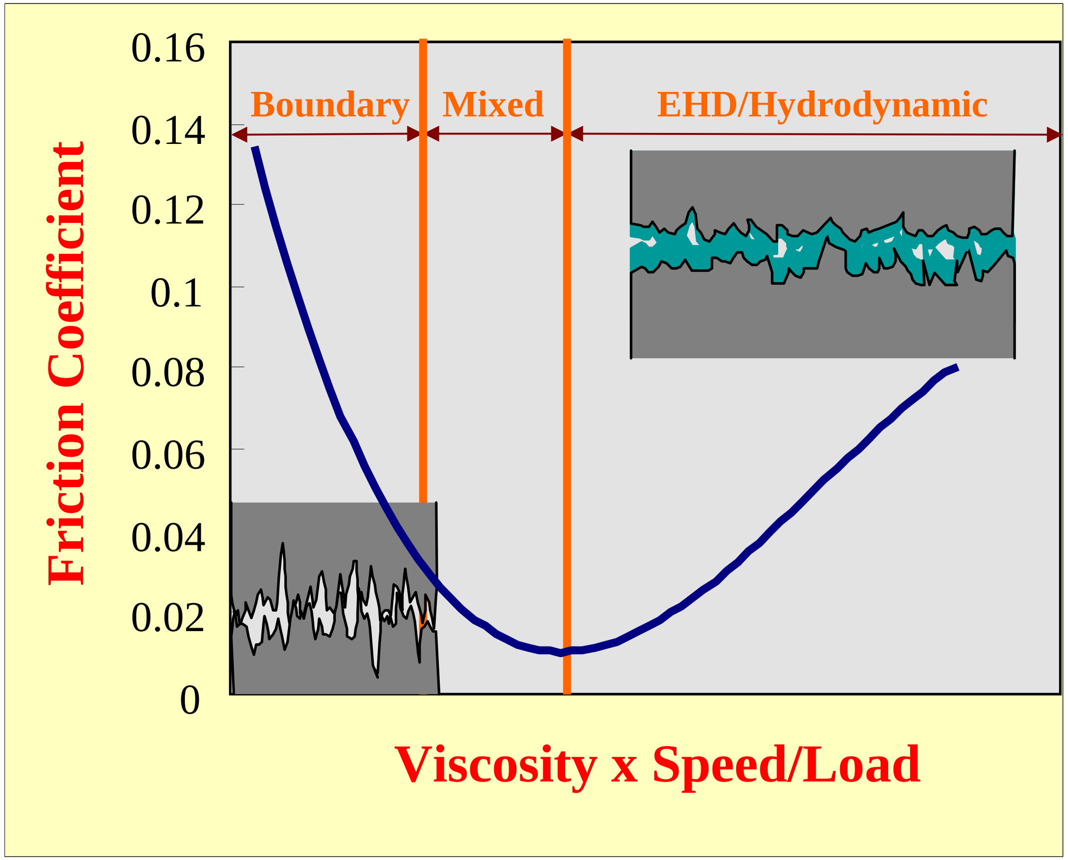
Why Valvetrain?

Direct acting mechanical bucket design offers the best opportunity to evaluate surface texture/coatings since this design operate in boundary/mixed lubrication regime.



Direct Acting Bucket Tappet

Stribeck Curve



Experimental Set-Up

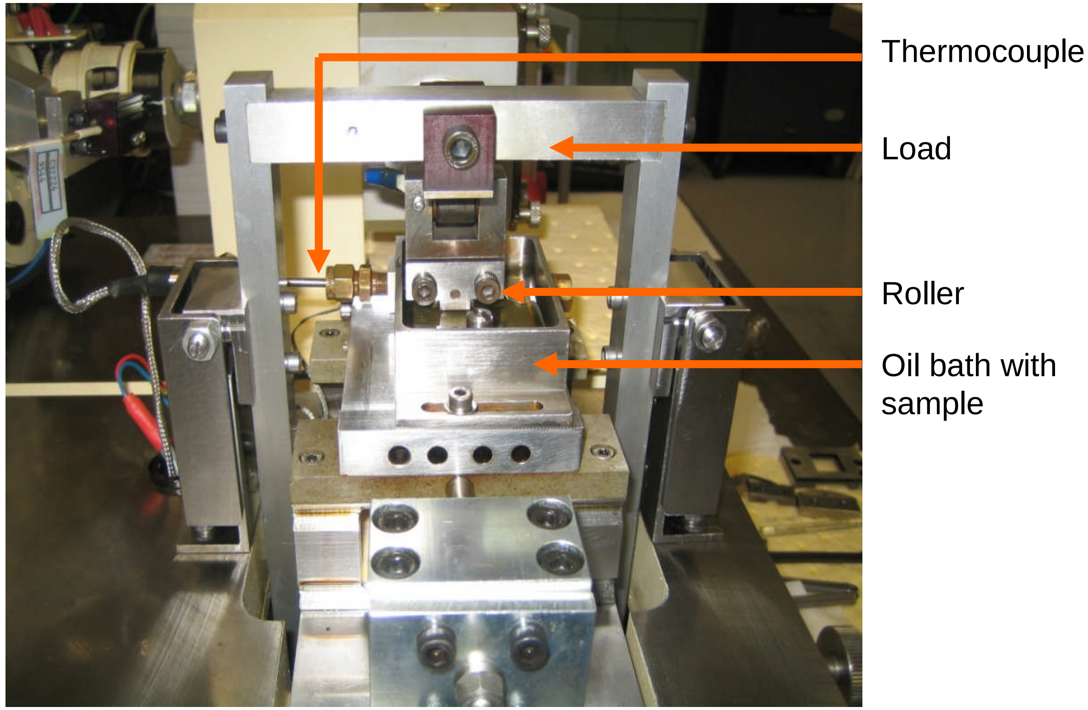
- Plint TE77 rig (Phoenix Tribology, UK)
- SAE 5W-20 viscosity grade GF-4 engine oil

Conditions:

- Test Time (1hr)
- Load (240 N)
- Specimen Temperature (40/80/100/120) ^{0}C

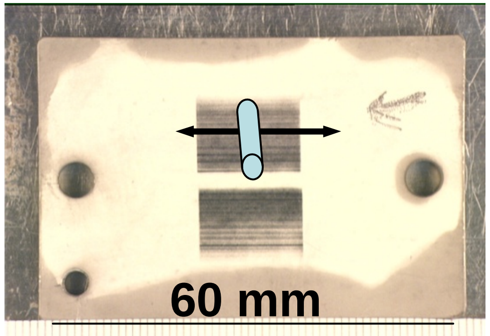
Measurables:

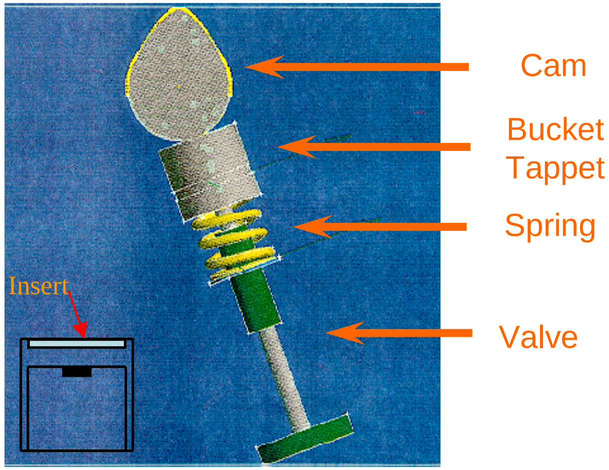
- Friction Force
- Friction Coefficient
- Contact Potential



Boundary Lubrication for Fixed Load and Fixed Speed

Parts Specification

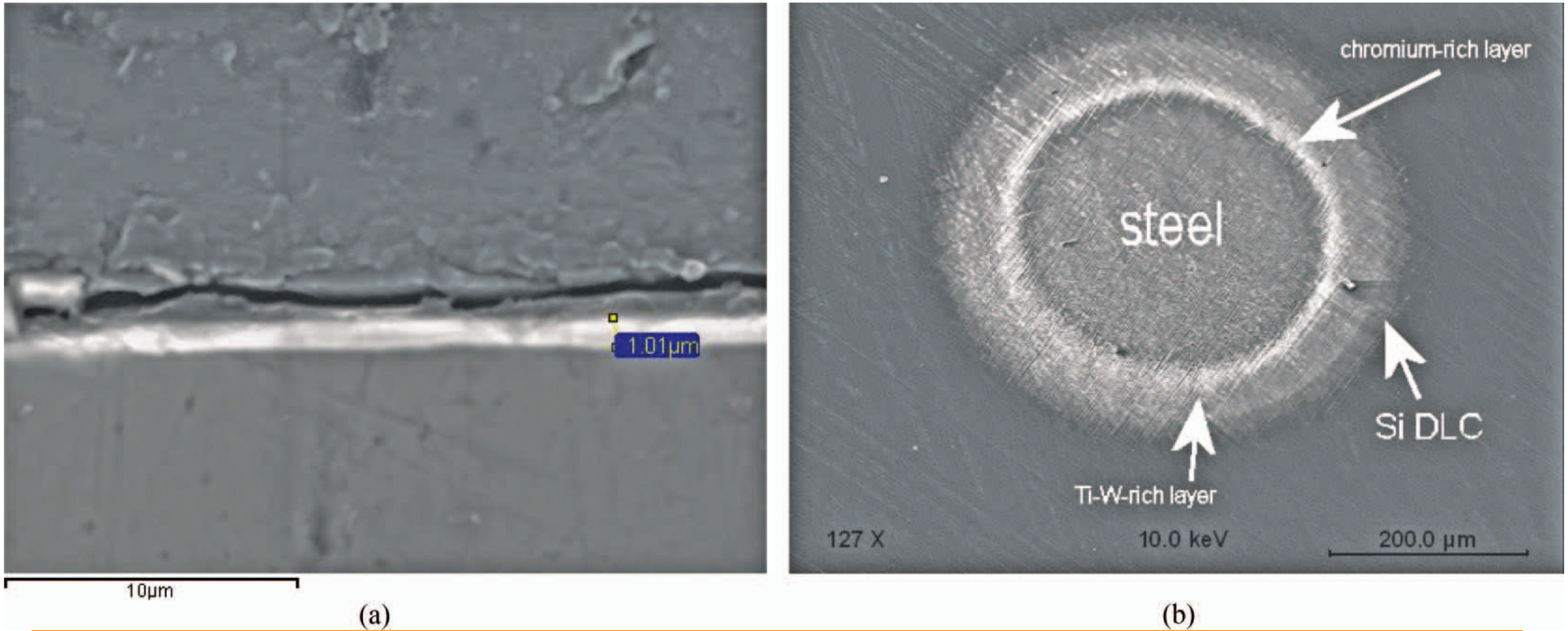




Direct Acting Bucket Tappet

	Material	Hardness	Surface Roughness, Ra
Plint tests			
Cylinder	AISI 52100 steel	82 HRA	0.28 μm
Flat	16MnCr5 steel	58 HRA	0.54 μm, 0.15 μm
DLC coating	a-C:Si	–2000 Hv	0.54 μm, 0.15 μm
Motored valvetrain tests			
Camshaft	Chilled cast iron	73 HRA	0.10 μm
Bucket tappet	Carbonitrided steel	76 HRA	0.04 μm

DLC Coating Thickness and Composition



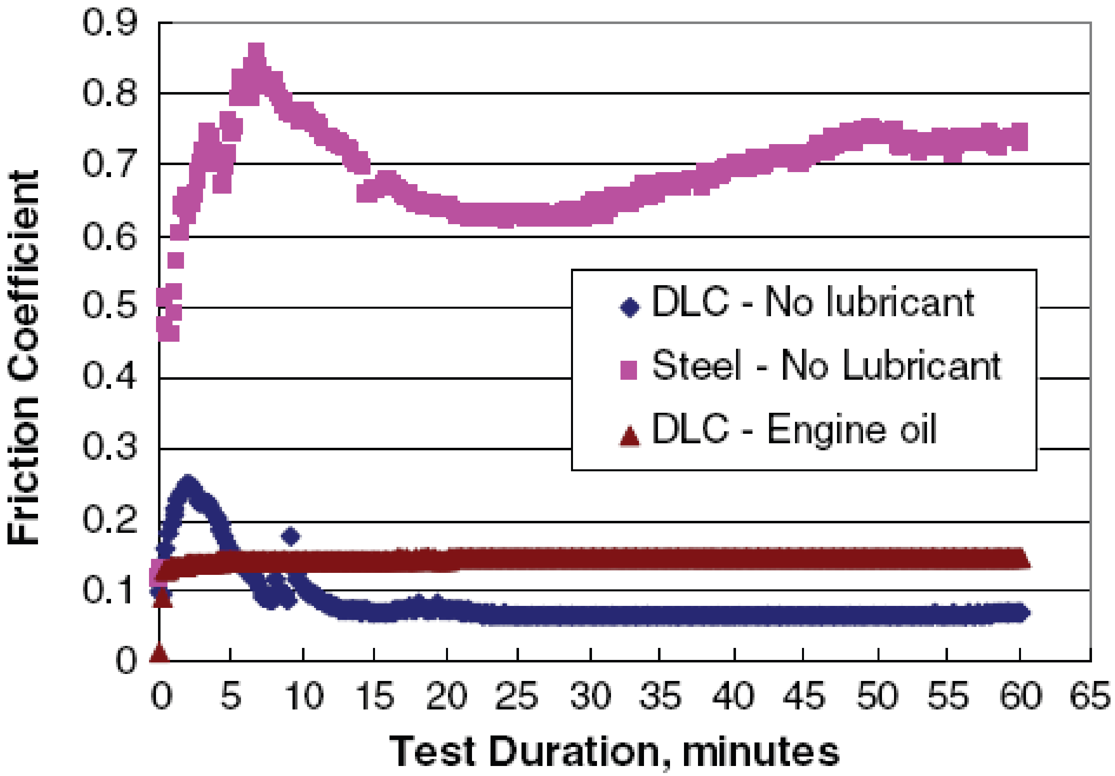
Scanning Electron Micrograph:

(a) Through the cross section of the coating and

(b) A crater on the coated surface showing various composition bands.

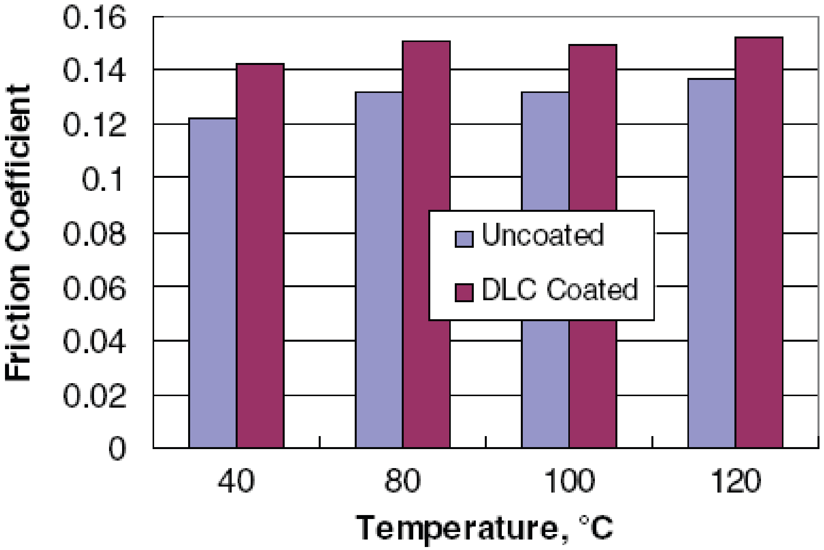
The purpose of depositing a multilayer coating is to improve adhesion on the steel substrate and tribological properties.

Friction Characteristics of DLC Coating

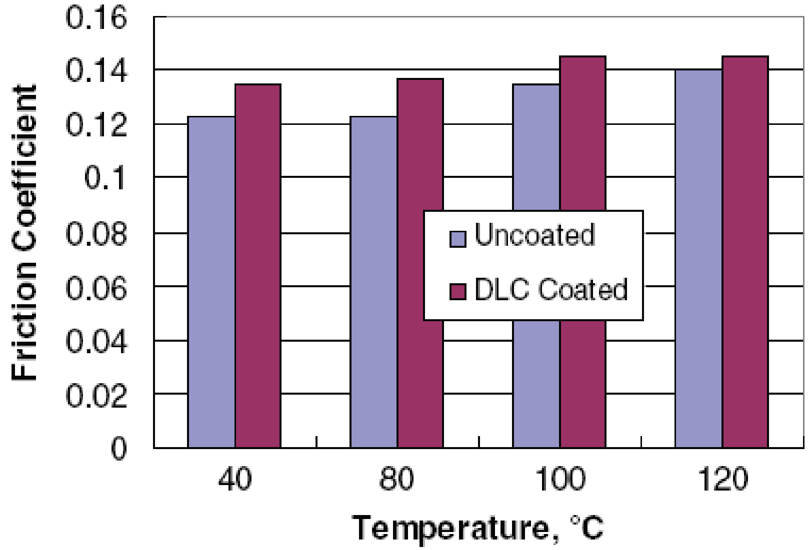


- The friction characteristics of DLC films as a function of test duration using polished (Ra = 0.15µ) flats.
- Friction coefficient remained relatively stable at about 0.08 (non-lubricated).
- The steady-state friction coefficient under the nonlubricated condition appeared to be lower than that of lubricated condition.

The friction characteristics of DLC coatings as a function of engine oil temperature



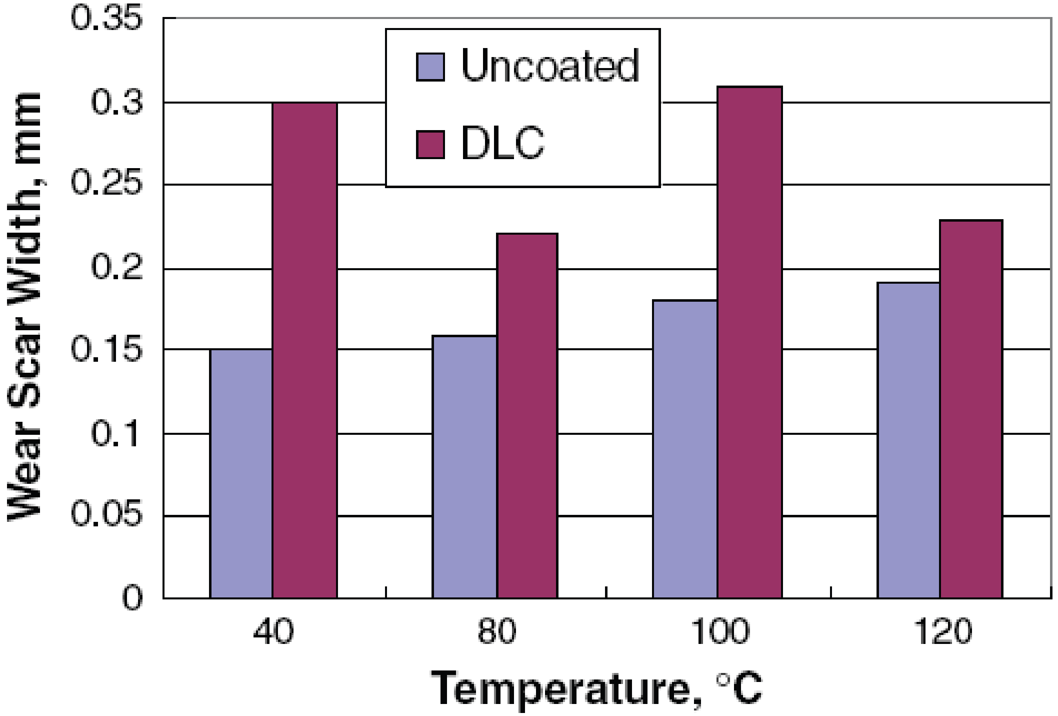
(a)



(b)

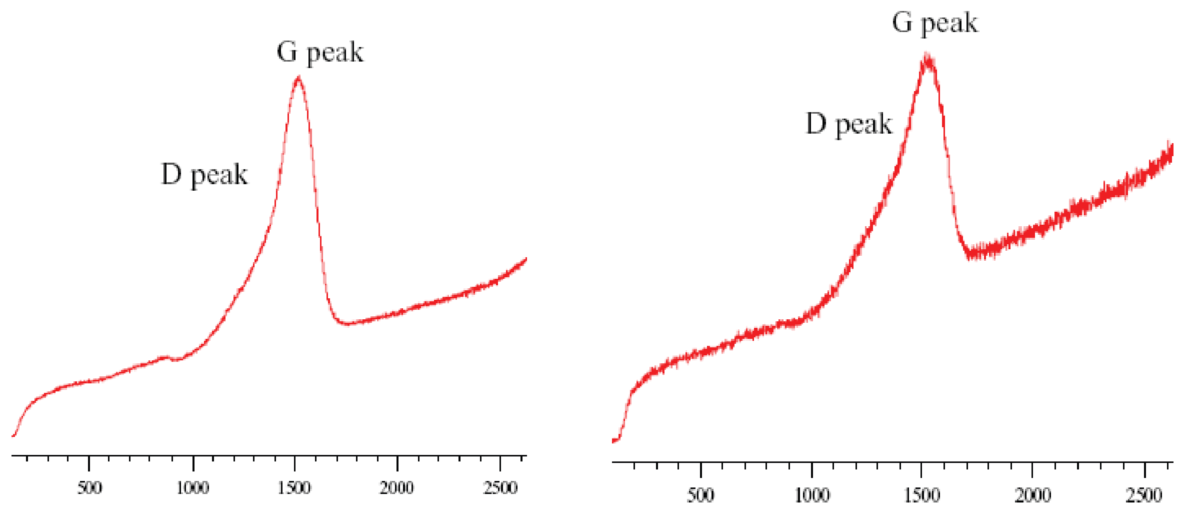
- The friction characteristics of DLC coatings as a function of engine oil temperature when the surface roughness of the flat is (a) 0.54 μm and (b) 0.15 μm.
- The friction coefficients increased slightly with the engine oil temperature and the friction coefficients of DLC coatings were a little higher than those observed with uncoated steel flats.
- Very little difference in friction coefficients when the surface roughness (Ra) changed from 0.54 to 0.15 μm.

Wear scar width of cylinders in contact with DLC-coated polished flats

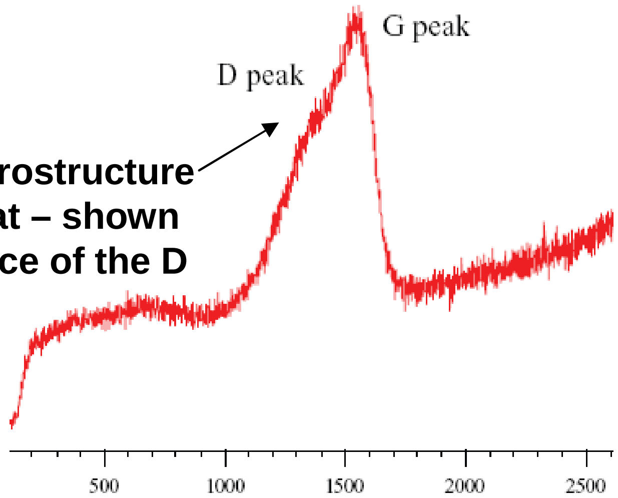


- The wear of the cylinder in contact with DLC-coated flats was much higher than that for uncoated flats.
- This could be due to increased surface hardness of the flat due to deposition of coating and/or the lack of formation of lubricant derived antiwear films as described later.

Raman spectra from an (a) unworn region, (b) worn area from a lubricated test at 100°C, and (c) worn area from an unlubricated test using DLC-coated flats



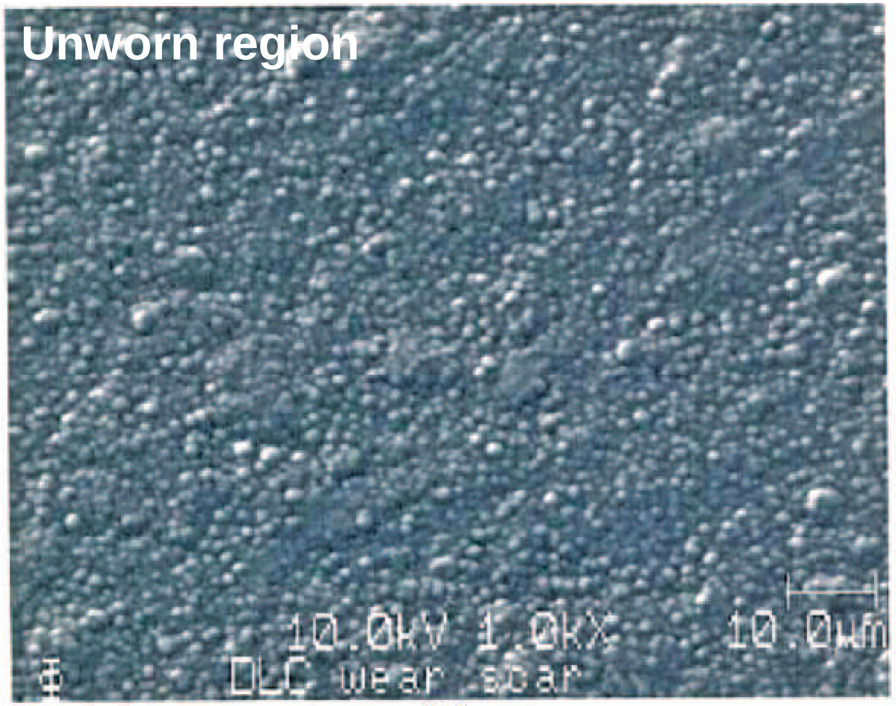
(a) (b)



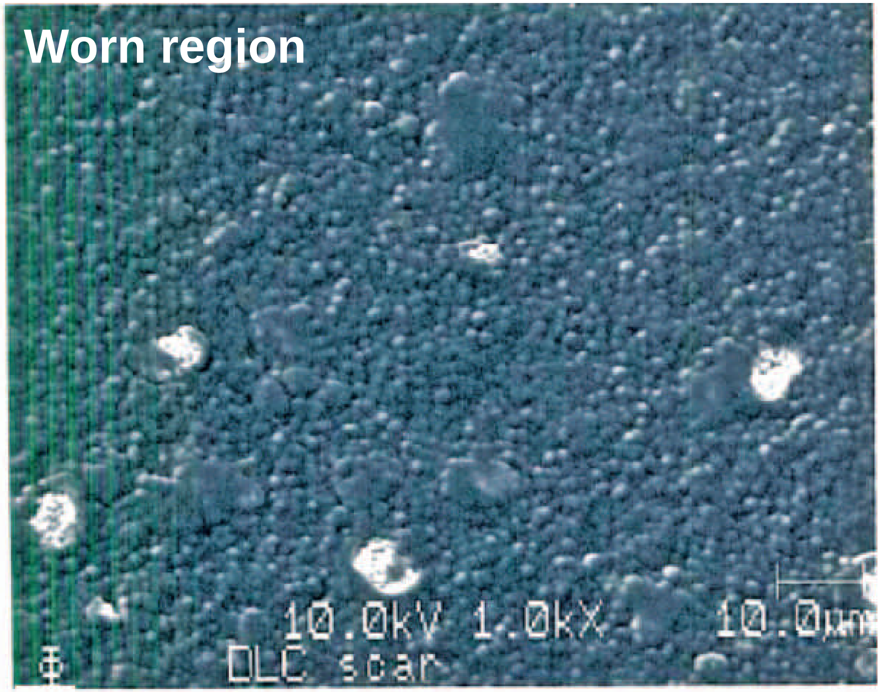
Change in DLC microstructure due to localized heat – shown due to the emergence of the D peak

- Unworn region shows a broad peak centered at around 1,550 cm^{-1}, which is known as the G peak, and a small broad band at 870 cm^{-1}.

SEM of DLC-coated Flat after a Lubricated Test at 100^{o}C (Plint Tests)



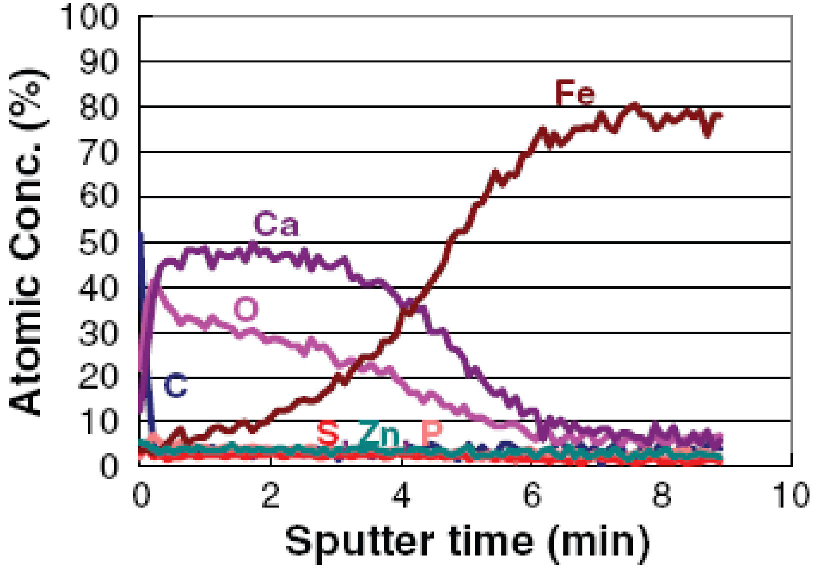
(a)



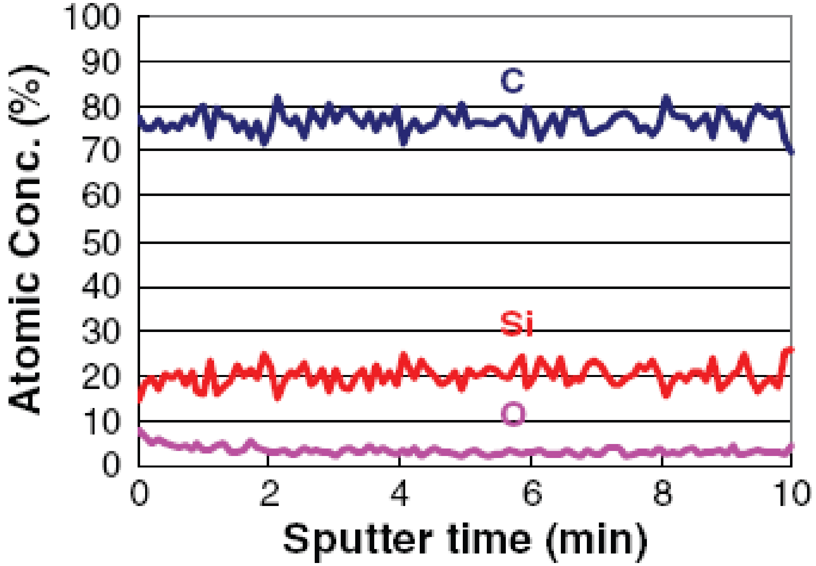
(b)

- Very little difference in the coating morphology between the worn and unworn regions.
- In the worn area several tiny, flat regions were created as a result of sliding
- A hard, wear resistant surface created by the deposition of DLC coating.
- Tiny white spots (worn area) appear as topographical defects in the SEM image.

Auger Depth Profile of Surface Films after a Lubricated Test at 100ºC (Plint Tests)



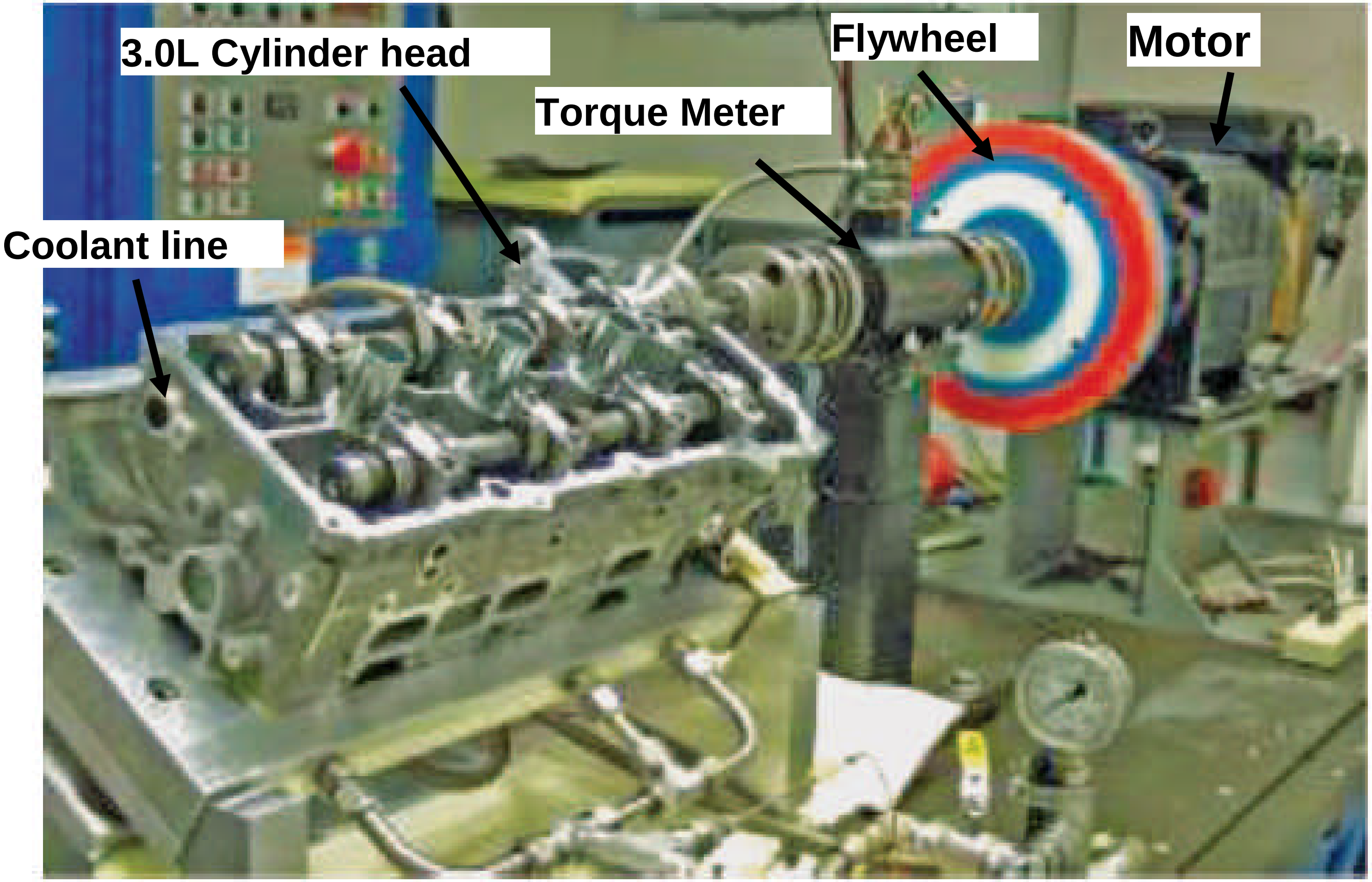
(a)



(b)

- Auger depth profile through surface films formed on (a) uncoated and (b) DLC-coated steel flat in the presence of lubricant at 100◦C (from Plint tests)..
- The general distribution of elements on the film was typical of an uncoated steel flat sliding against another steel counterpart in the presence of engine oil and in general was responsible for antiwear protection.
- The worn surface contained C and Si, the components of the DLC coating. This result suggests lack of any interactions between the lubricant additives and the DLC coating.

Friction Measurement
Component Level Test



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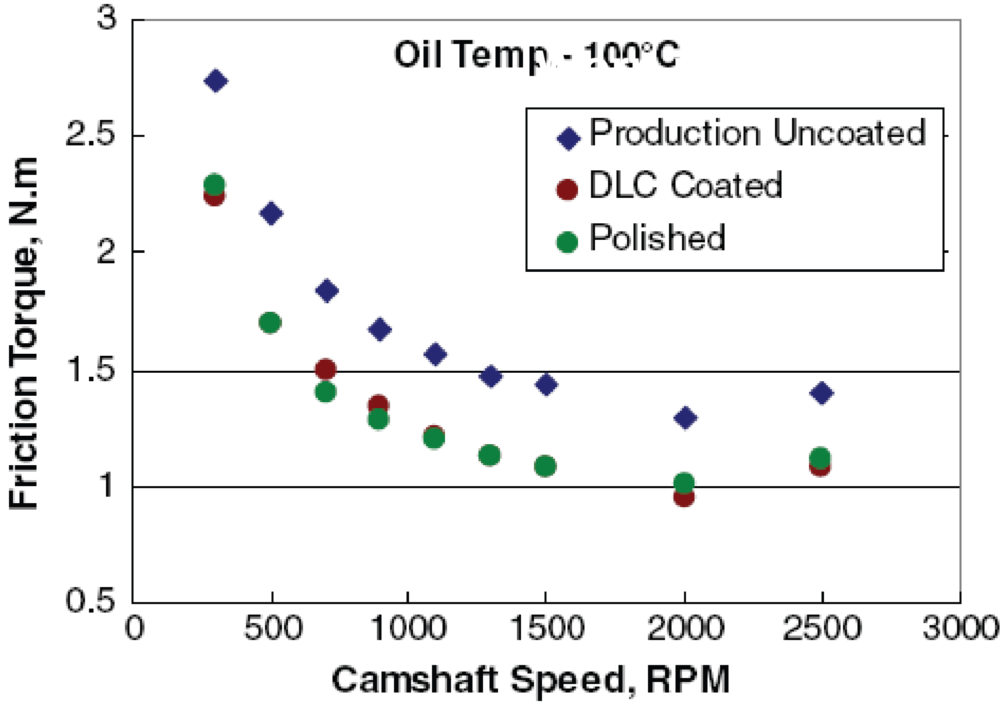
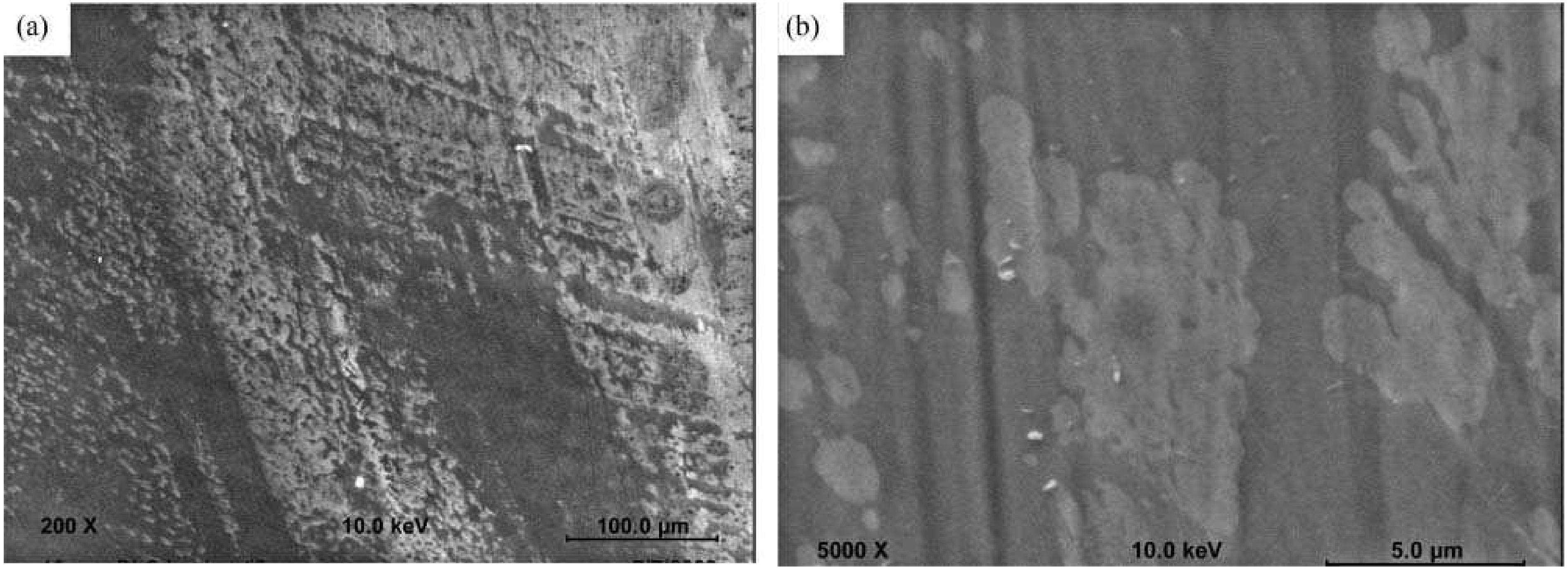
Friction Torque as a function of Camshaft speed at 100°C oil temperature



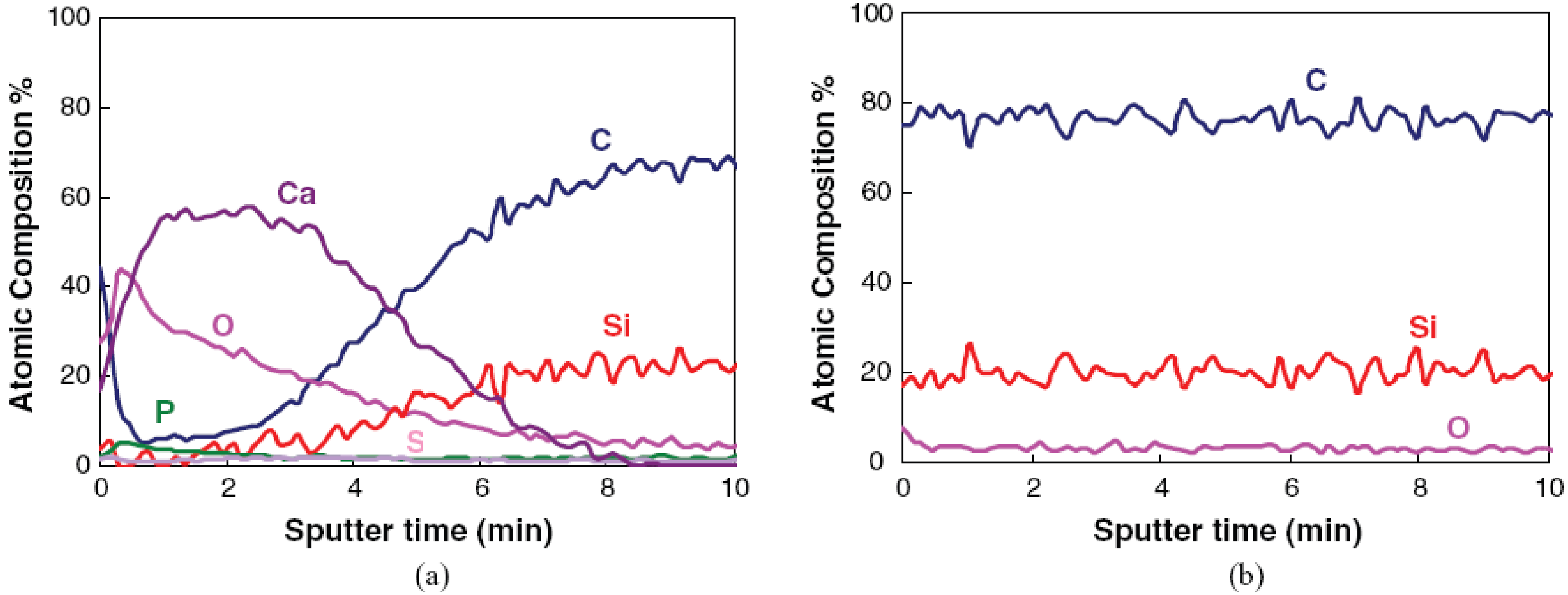
- The friction benefit observed with polished buckets compared favorably to DLC-coated buckets.
- Because the surface roughness of polished and DLC-coated buckets is the same, the data suggest that the DLC coating did not offer any additional friction reduction benefit.

SEM of worn region on the DLC-coated bucket tappet.



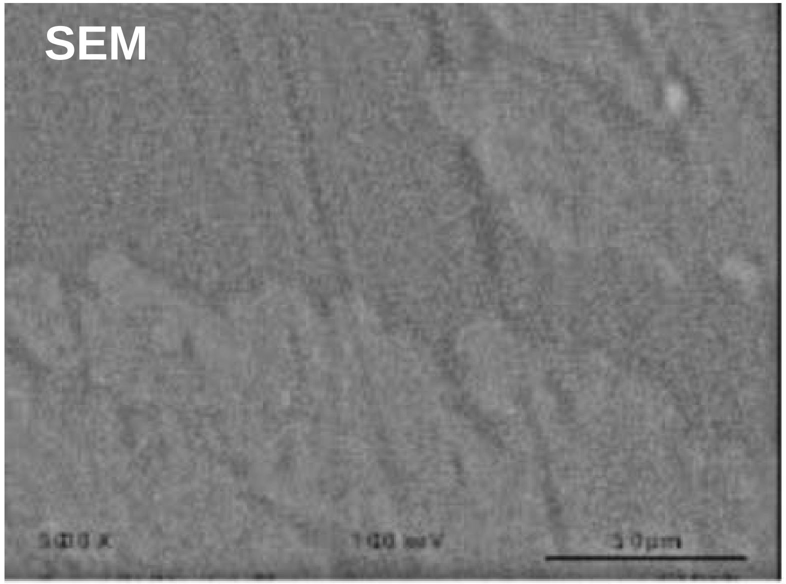
- (a) at low magnification showing the distribution of films and (b) at higher magnification showing film morphology
- The lubricant-derived film appeared white in the scanning electron micrograph and could be identified distinctly on the DLC coating background, which appears dark

Auger electron spectra of (a) light region and (b) dark region on DLC-coated bucket tappet surface

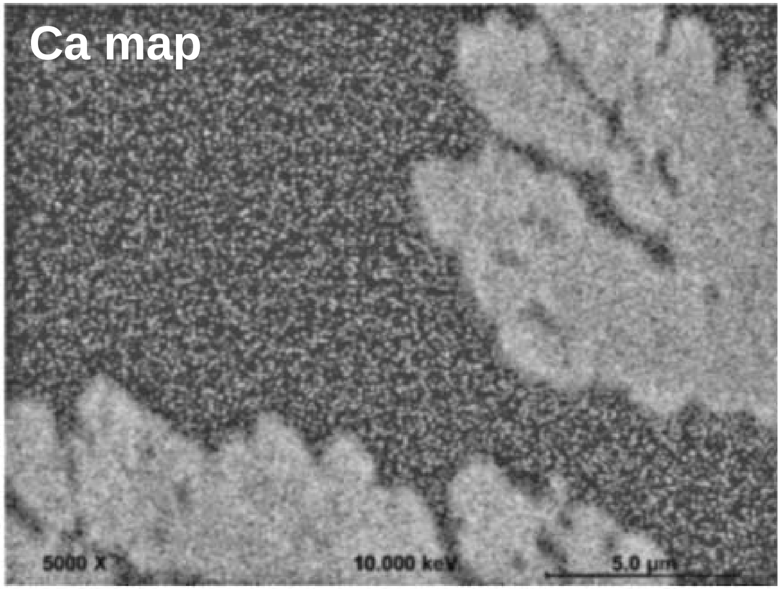


- Light region show high concentrations of O and Ca on the surface. Some Zn, S, and P, the elements from ZDDP, was also found on the surface
- Darker regions did not contain any of the lubricant-derived elements but primarily contained C and Si

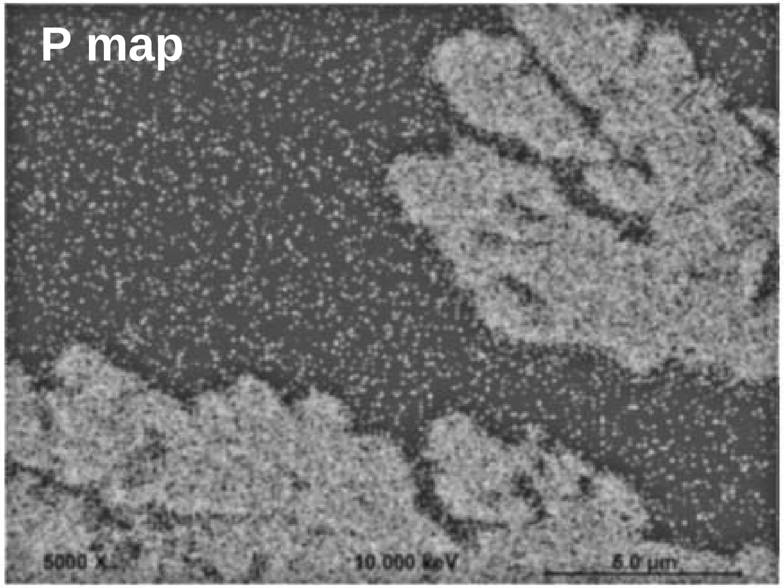
Wear region on DLC-coated bucket surface (a) SEM, (b) Ca map, & (c) P map



(a)



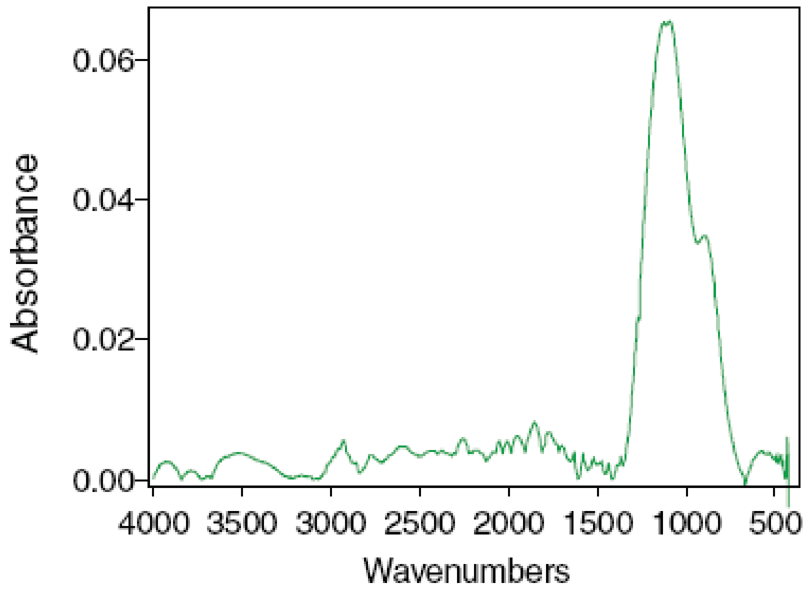
(b)



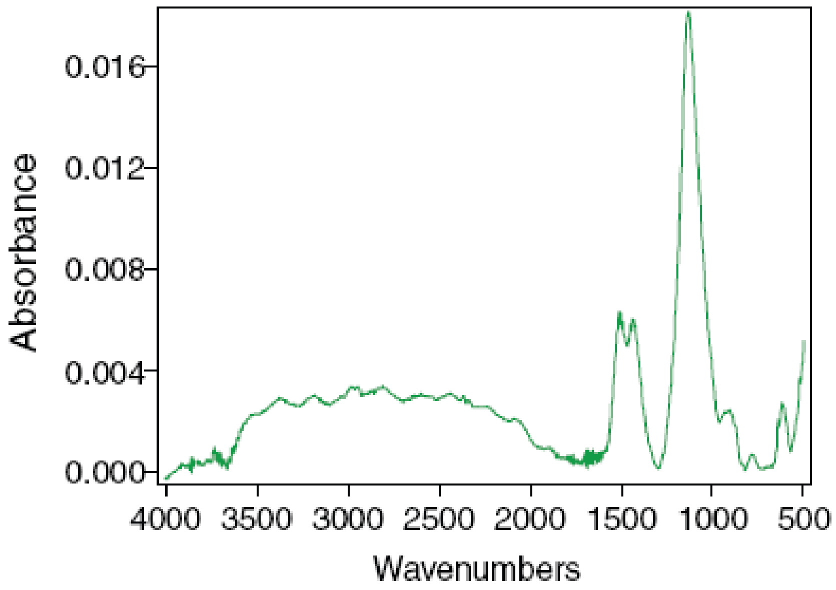
(c)

The Ca and P maps are practically superimposed on each other, which shows that both elements are present in the lubricant-derived films.

Infrared reflectance–absorbance spectra of (a) polished DLC-coated bucket and (b) polished uncoated bucket.



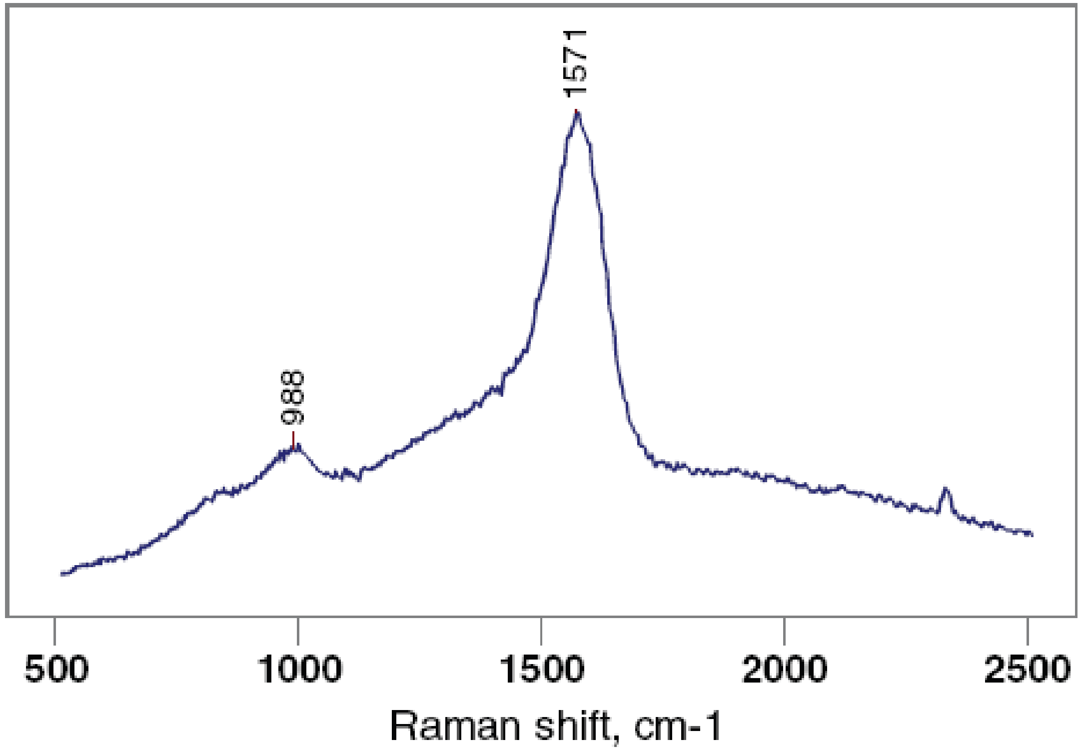
(a)



(b)

- The strong peak at around 1,150 cm^{-1} is associated with phosphate type inorganic compounds, and the peaks at 1,441 and 1,511 cm^{-1} are associated with carbonate material deposited due to interactions of detergents with the surface.
- The broad band centered at 3,000 cm^{-1} is indicative of –OH groups and is involved in hydrogen bond–type interactions. Phosphate bands at 1,133, 1,094, and 908 cm^{-1} were also found on the DLC-coated buckets.
- The carbonate peak was present on the uncoated bucket but was absent on the DLC-coated bucket.

Raman spectrum of tribofilm on DLC-coated bucket-tappet



- A 244-nm (UV) Raman spectrum obtained from the surface of the DLC-coated bucket, which showed the characteristic carbon peak of DLC coating at 1,571 cm^{-1}.
- In addition, the peak at 988 cm^{-1} is typical of phosphate films, further confirming that the surface film on DLC coating is phosphate containing.
- No peak for carbonate was seen.

Conclusions

- DLC coating investigated in this study showed significant reduction in friction coefficient compared to steel sliding on steel, possibly due to the formation of a transfer film.

- In the presence of engine oil friction coefficient was slightly higher than that observed in the absence of the engine oil, possibly due to the lack of a transfer film formation.

- In boundary lubrication conditions, the wear of the counterface steel cylinder in contact with a DLC-coated flat was higher than that against uncoated steel flats, probably because of high hardness of DLC coating and also because of the absence of any lubricant-derived antiwear films on the coated substrate.

Conclusions (contd…)

- Raman spectroscopy data suggest a transformation in the microstructure of the DLC coating under unlubricated sliding.

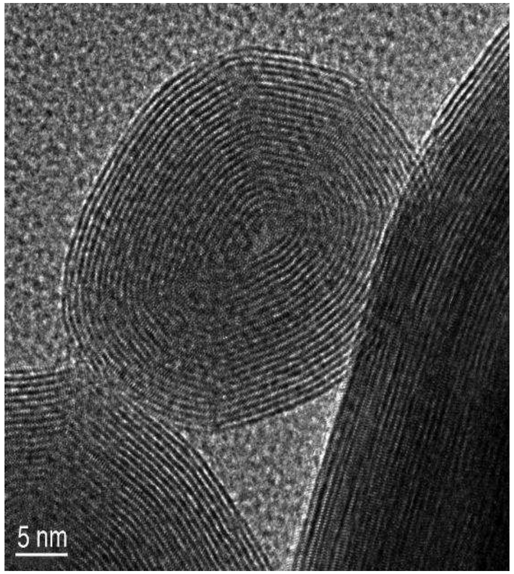
- In motored valvetrain tests, under mixed lubrication conditions, both polished and DLC-coated steel bucket tappets showed lower friction torque than the production bucket tappets.

- Based on IR, auger, and Raman spectroscopy results, the film appears to primarily consist of calcium phosphate, which is different from the mixture of phosphate-type inorganic compounds and carbonates previously observed on uncoated steel surfaces.

Nanomaterials in Lubricant Industry

(due to confidentiality issues information on this material is limited)

AddNano Consortium



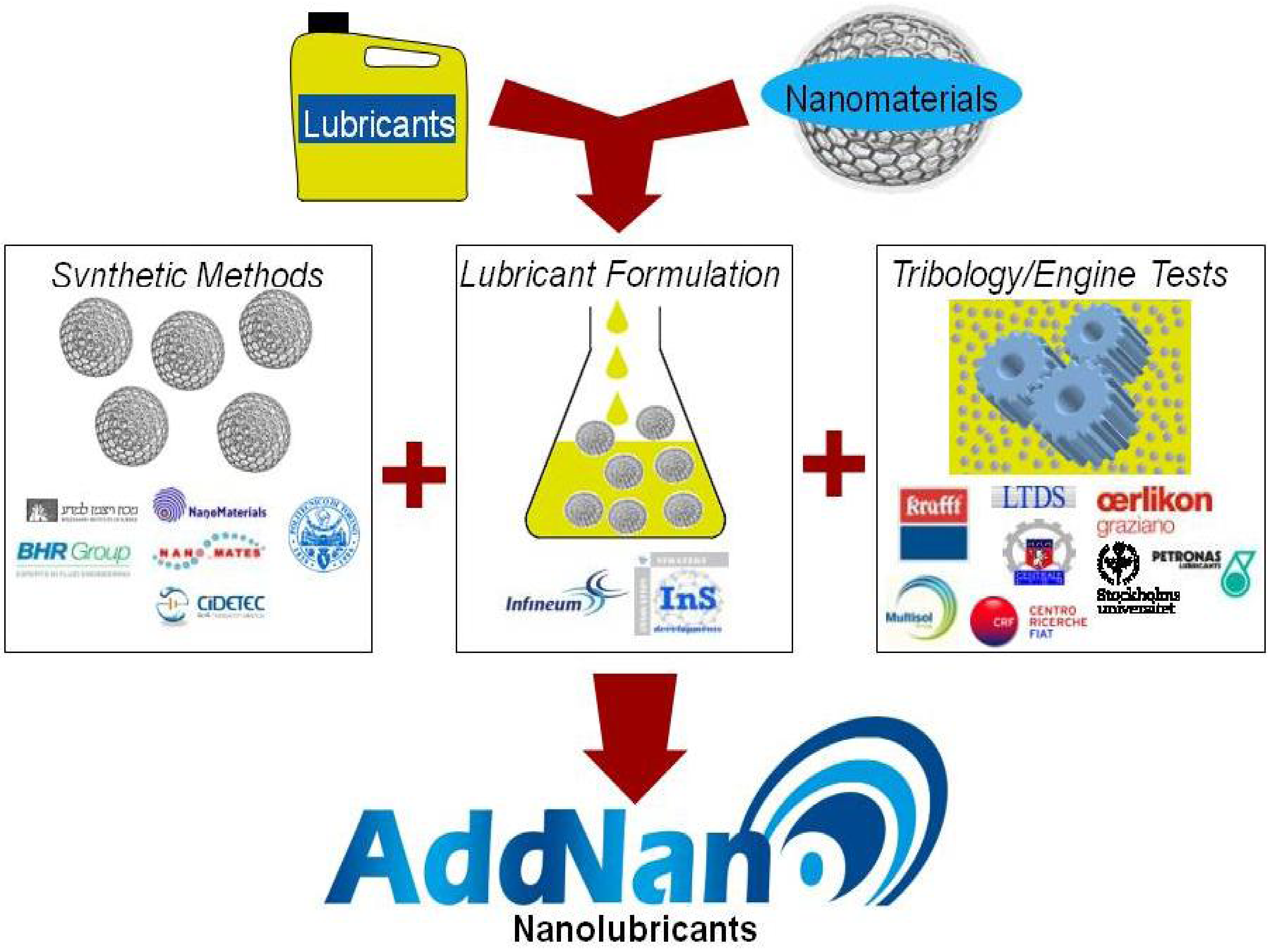
AppNano

Petronas

Fiat Powertrain

- **The AddNano project is partially funded by European Commission within the 7th Framework Programme (NMP-2008-1.2.1) and its overall objective is to overcome the technological barriers involved in the development of large scale market introduction of a new generation of lubricants incorporating nano-materials.**

AddNano Consortium



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Thank You!