Innovation in Motion

# IMFair 2011

# PVD High Performance Coatings for Aerospace Applications

## Teer Coatings Limited, Miba Coating Group


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# Outline of Presentation

- Company Profile
- Miba Coating Group
  - High Tech Coatings GmbH
  - Teer Coatings Limited
- Physical Vapour Deposition for Aerospace Applications

# No Power Train without Miba Technology

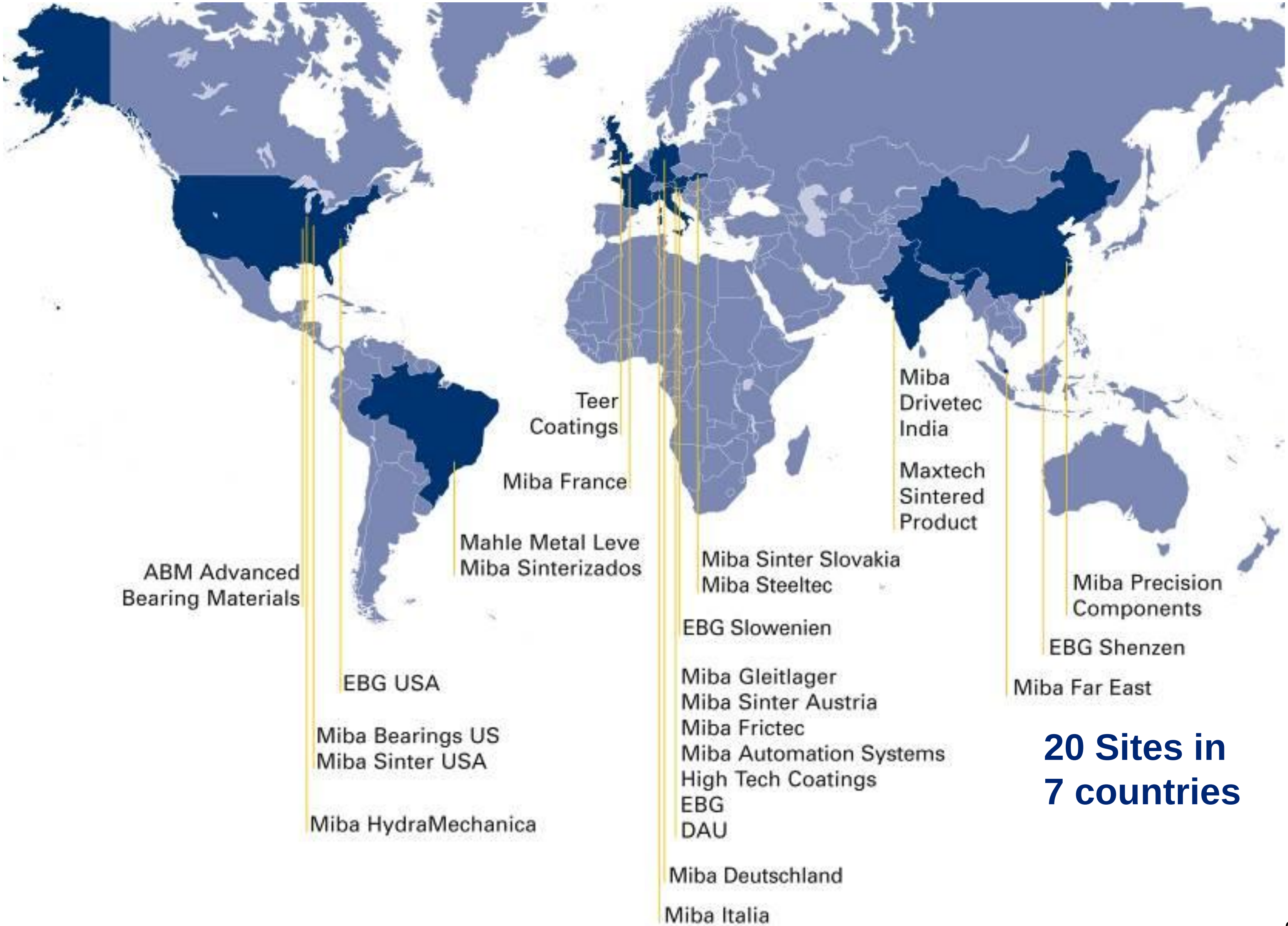








# Global Network




**20 Sites in 7 countries**

# Employees and Values

## Facts

- 3,600 employees worldwide
- 1,800 in Austria
- 118 apprentices in Austria

## Values

- Technology Leadership
- Entrepreneurship
- Passion for Success
- Life-Long Learning

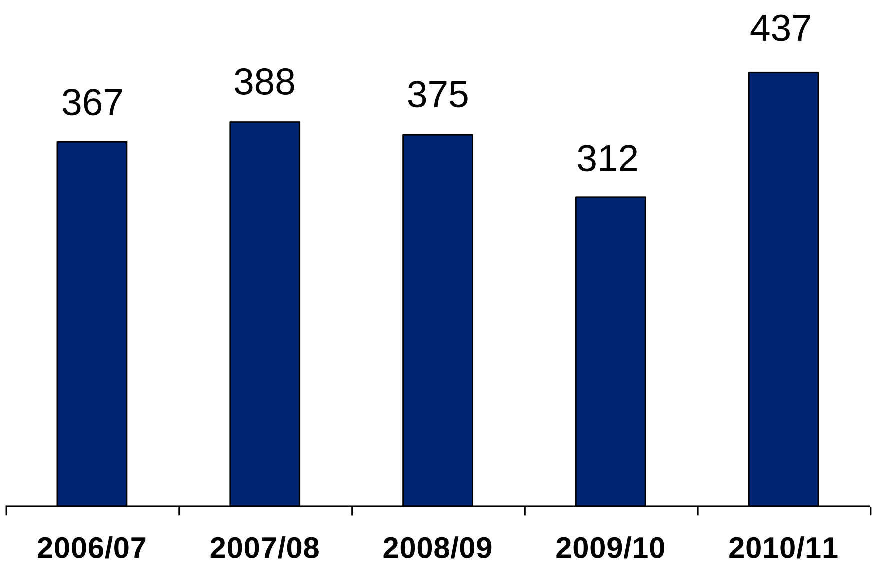
# Research and Development

**Technology Leader Miba (2010/11)**

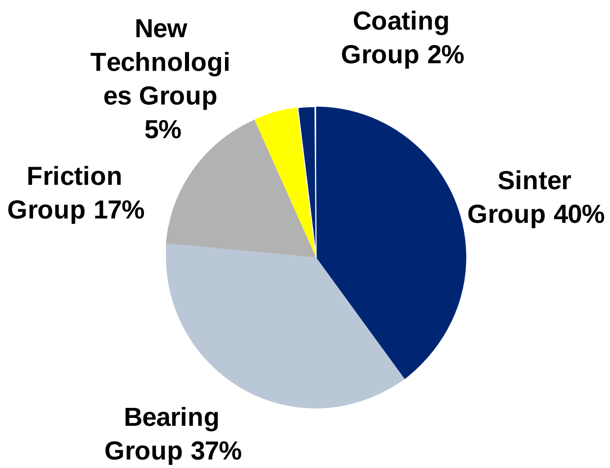
- R&D expenditure equivalent to 5% of sales
- R&D expenses: 22,6 million euros
- 167 employees in R&D
- 166 valid patents and petty patents

# Profitable Growth

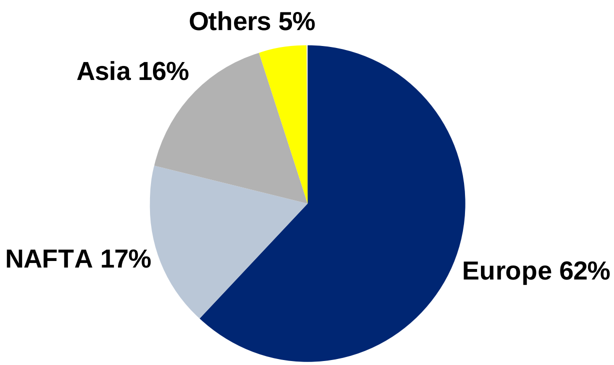
Sales in million euros




by Division (2010-11)




by Market (2010-11)

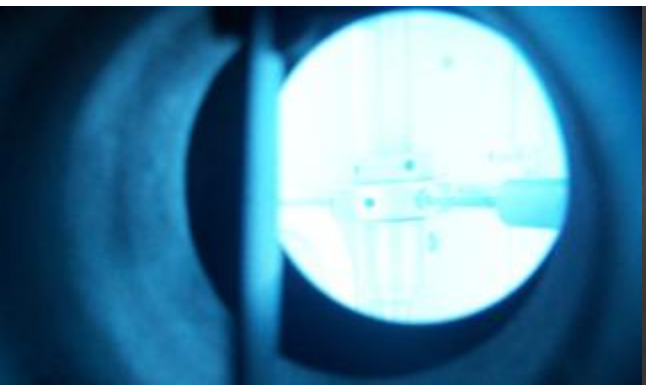


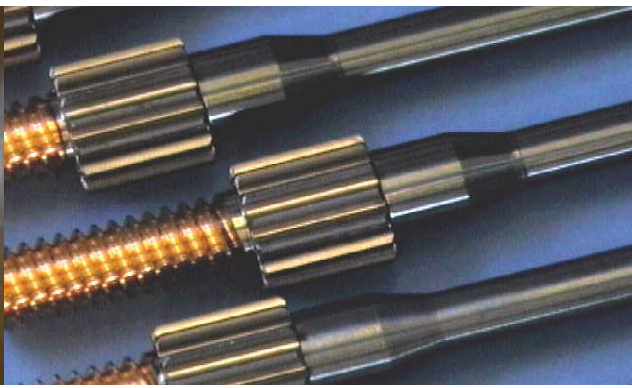
# High Tech Coatings GmbH

HTC develops individual coating solutions. Polymer coatings, electroplated overlays and PVD coatings are the core technologies. Moreover, HTC is a specialist in highly efficient high volume production.
HTC partners with the international automotive industry in development activities.

HTC is ISO9001:2008 and TS 16949 certified.

# Teer Coatings Ltd.





Teer Coatings deposit PVD thin film coatings using a patented magnetron sputtering technique developed in-house.

TCL has the capability to deposit one of the widest range of coatings available anywhere in the world.

Research & Development play a crucial role within technology-focused TCL.

TCL is ISO9001:2008 certified.

# Examples of Existing Aerospace Applications

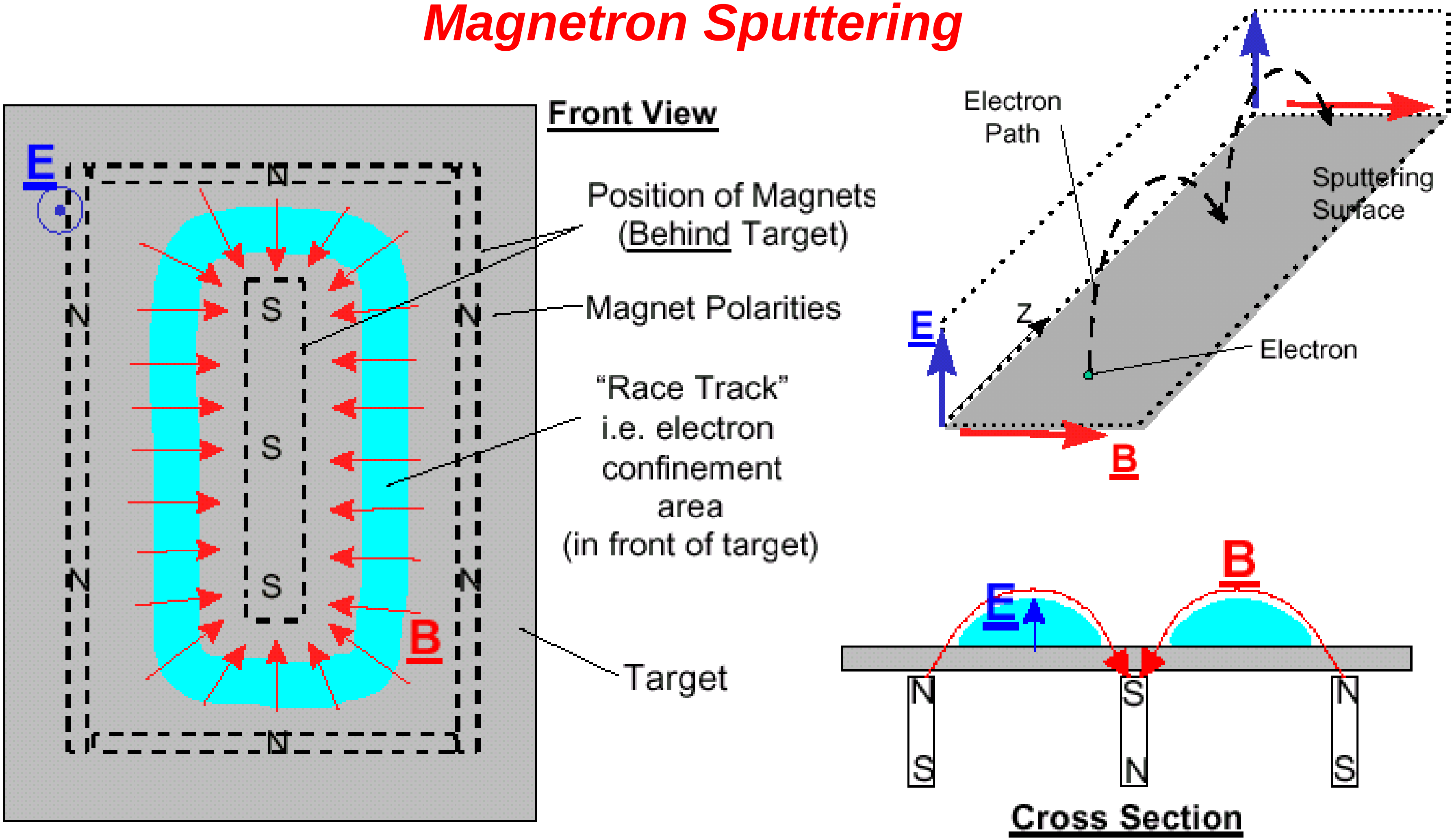
- Miba Coating Group, Teer Coatings Limited:
  - friction reduction: guide pins, solenoid components, valves, spindles, trunnions, sleeves, hinges (satellites) etc.
  - wear and environmental resistance: levers (TiN), pins (CrTiAlN).
  - electrical conductivity: noble metal for electrical screening.
  - currently at least14 aerospace-related customers.
- Miba Bearing Group:
  - CuPb Bearing bushings (i.e. a solid component, not a coating!).
    - used in Turbo Prop PT6 engine.
    - > 10 years successful production experience.
    - Pratt and Whitney approval.

# High Performance PVD Coatings for Aerospace

- Introduction to Magnetron Sputtering-based PVD.
  - Low friction, self-lubricating coatings.
  - Wear resistance, inc. multi-element , nanostructured nitrides.
- Potential applications for components:
  - Improve surface performance of lightweight materials.
  - Protect in aggressive environments (high temperature, high loads, fretting, abrasion, erosion, oxidation, corrosion, etc.).
  - Reduce parasitic losses, improve efficiency.
- Potential applications for tooling:
  - Cutting tools for difficult materials.
  - Micro-machining.
- Other functional applications:
  - Fuel cell components, catalysts, optical films, sensors, etc.

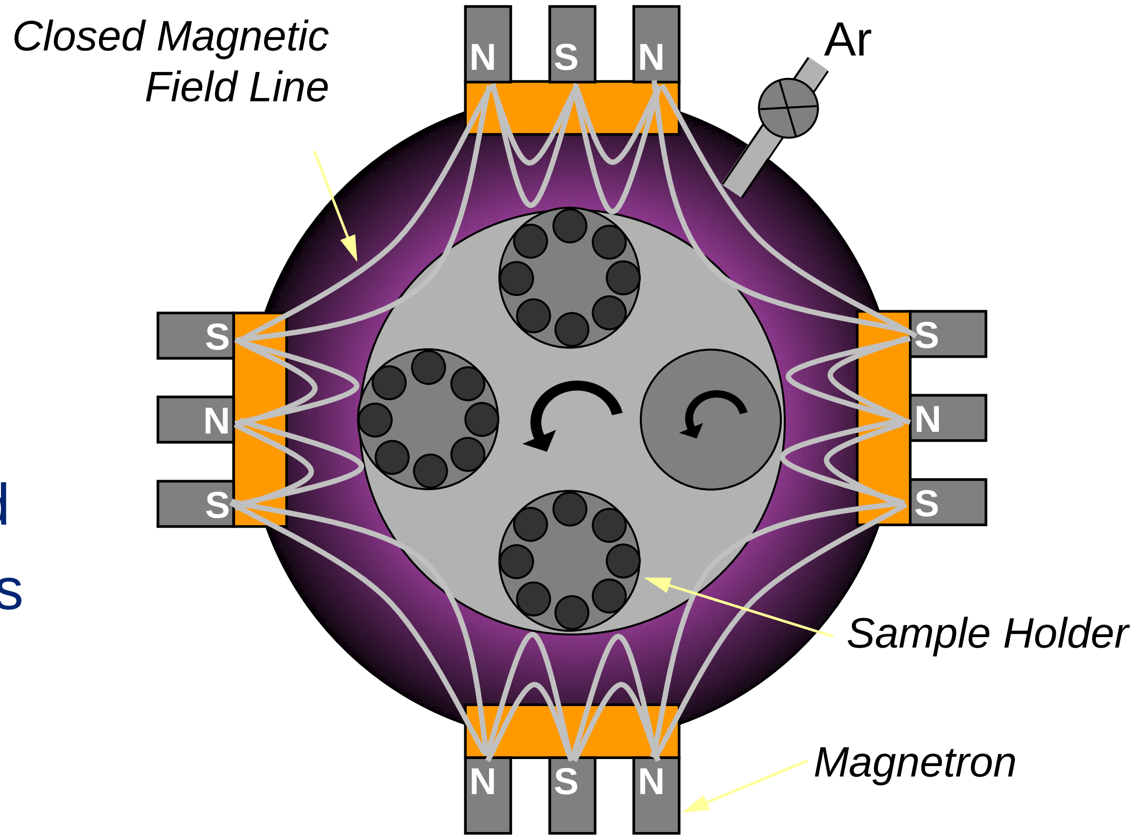
# Physical Vapour Deposition

## *Magnetron Sputtering*



# Closed Field Unbalanced Magnetron Sputter Ion Plating

- Unbalanced field
- Field lines "closed" with another magnetron
- Plasma confined around substrates
- Electrons and ion loss to chamber walls minimised
- Dense, adherent coatings




*UK Patent 2 258 343, USA Patent 5 556 519, EU Patent 0 521 045*

# High Rate, Automated Industrial PVD

- Miba has specialised PVD for the high rate coating of bearings.
- TCL has proven, industrial coating equipment for PVD batch production.
- Load-locked “in line” equipment facilitates semi-continuous operation.
- “Barrel Coating” for industrial PVD of powders and grits, fasteners, etc.

*Miba Gleitlager, Miba Bearings, Austria*


*Load Locked Barrel Coating System*

*In Line Coating System, TCL, Droitwich*

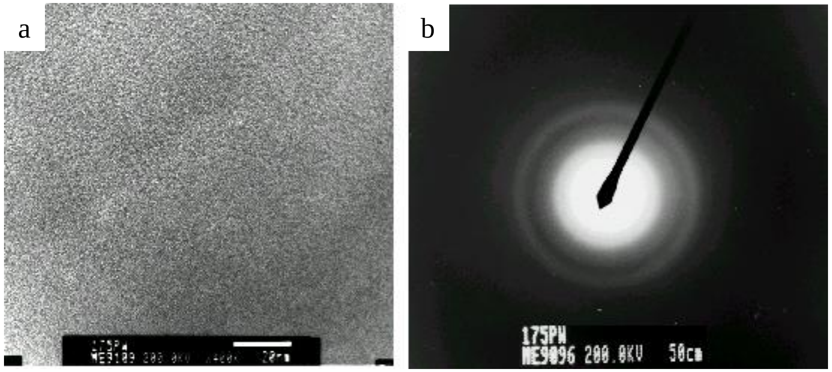
# Low Friction, Self Lubricating Coatings

- Self lubricious, low coefficient of sliding friction combined with high load bearing capability and toughness.
- Sophisticated coatings, designed with graded interfaces.
- Transfer layer mechanism can protect the counterface.
- Can also be used in combination with a hard underlayer.
- TCL Graphit-iC™:
  - Carbon-based, non-hydrogenated, electrically conductive.
- Dymon-iC:
  - Carbon-based, hydrogenated, “DLC”, electrically insulating.
- TCL MoST™.
  - $MoS_2$-based, humidity tolerant, but also qualified for space applications

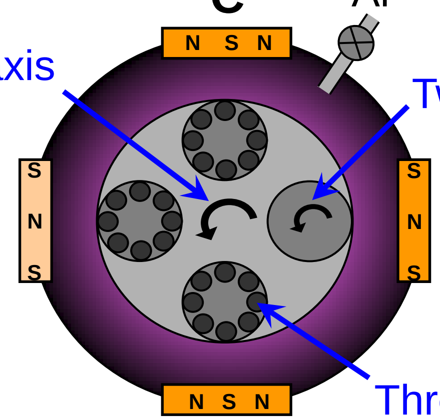
# TCL Graphit-iC™

- Metal doped carbon-based coating, H-free
- Coating Characteristics
  - Thickness 2.5µm
  - Hardness 1,400 – 2,200 HV
  - Coefficient of friction 0.05 – 0.09
- Properties
  - Very good in aqueous environments
  - High load bearing capacity
- Typical Applications
  - F1 and high performance motorsport
  - Fuel injection systems
  - Mechanical seals
  - Injection moulding tools
  - Tool coatings – e.g. for cutting Al-alloys

*S Field*

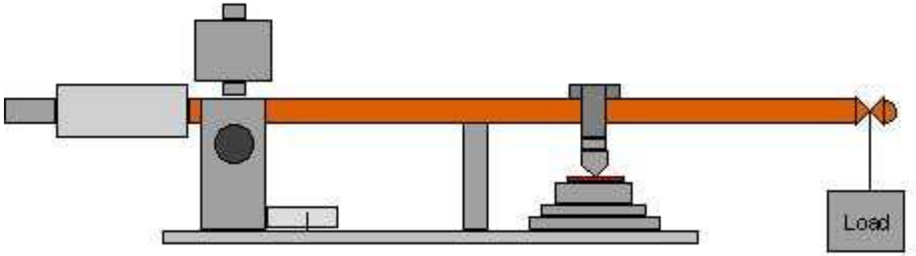



*TEM Cross Section & SAD*



# Assessment of Wear Resistance

***Pin on Disc Testing***




Typical conditions:

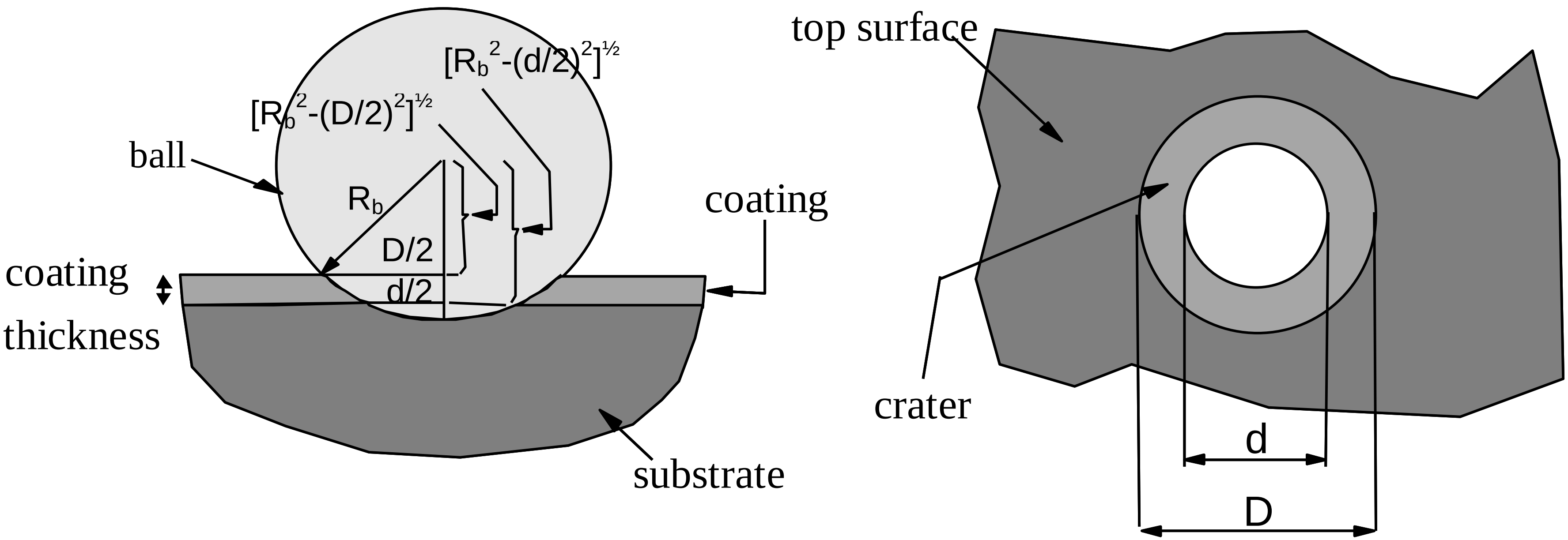
80N, 200 $mms^{-1}$, 720m

- ∅ 8mm
  - 477rpm = 28krevs
- ∅ 10mm
  - 382rpm = 22krevs

If wear depth ~0.2μm
$\Rightarrow \sim 10^{-11}$m/rev

# Assessment of Wear Resistance

## *Macroscopic Wear Testing*




Ball crater produces taper section profile that can be used to estimate coating thickness

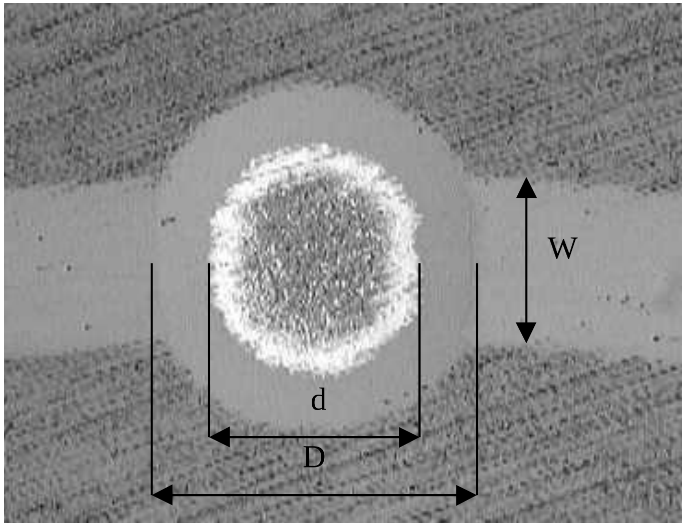
- technique can also be applied within the wear track

# Assessment of Wear Resistance

## *Macroscopic Wear Testing*

Simplification:

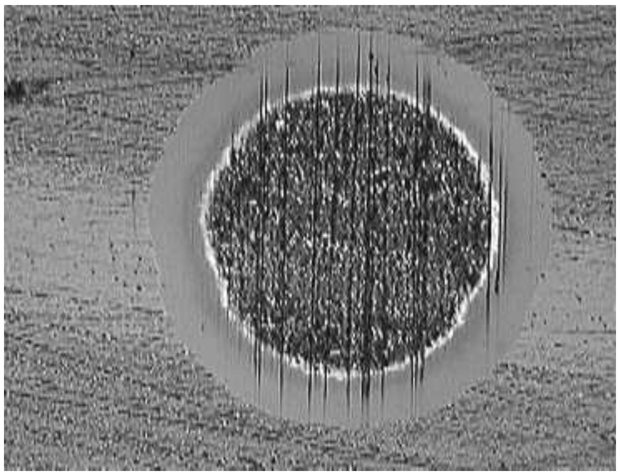
- assume triangular track profile
- wear depth ($w_d$) = (unworn thickness) *minus* (worn thickness)

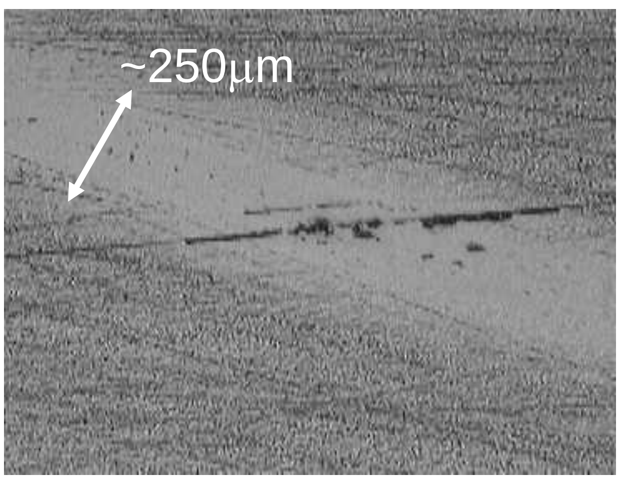



$$\text{Specific wear rate}\left(\frac{m^3}{Nm}\right) = \frac{(w \times w_d)}{\text{Load} \times 2 \times \text{rpm} \times t}$$

*(courtesy J Stallard, PhD Thesis, Nottingham University, 2005)*

# Graphit-iC: Testing under Oil






Pin-on-Disc,
Ø5mm WC-Co ball,
80N load,
100mm/s,
10W30 oil (submerged)

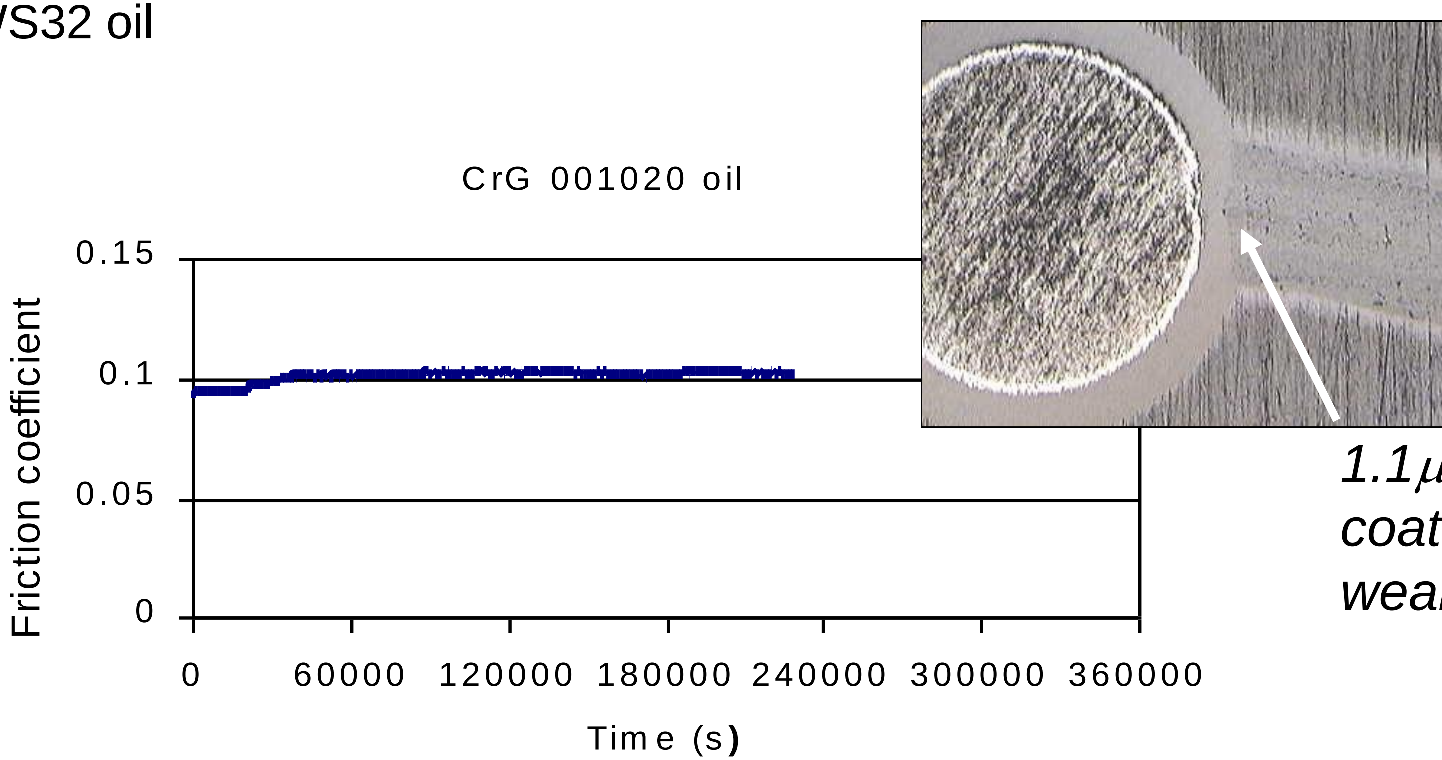
20 hours testing (=7.2km):

**SWR<7.5x10$^{-19}$m$^{3}$/Nm**

*i.e. below instrumental resolution*

# Graphit-iC: Testing under Oil

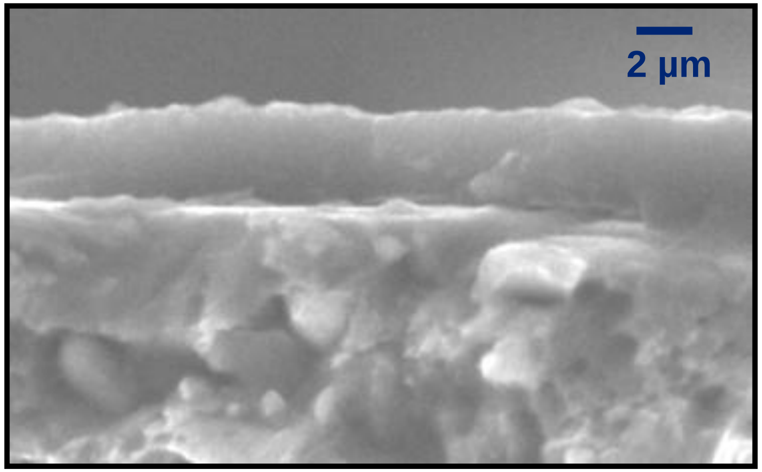
PoD: ϕ5mm WC-Co ball, 100N load, 300mm/s,
AWS32 oil

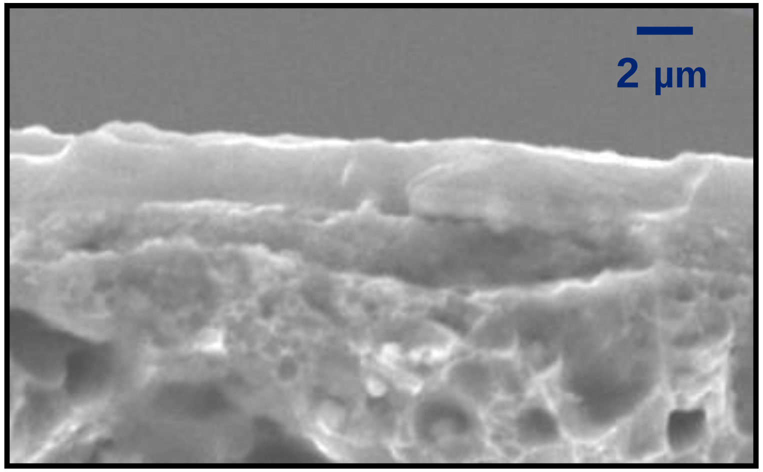



*1.1 μm coating wear*

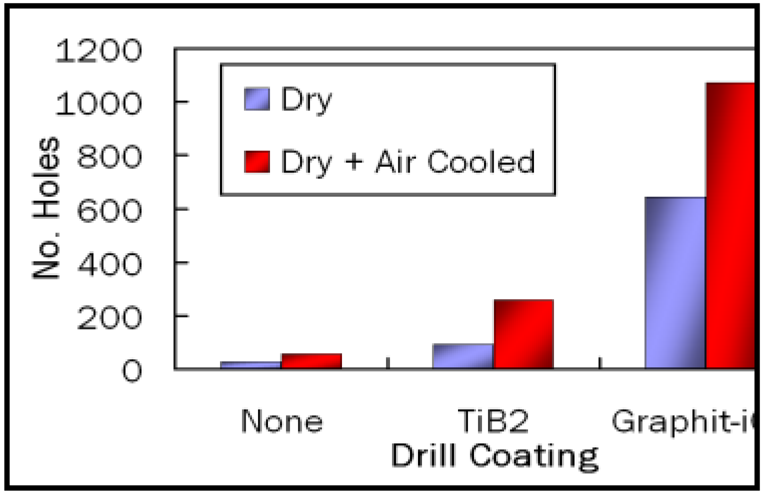
64 hrs (=69km): SWR $=7.7 \times 10^{-19}$ $m^3/Nm$

# Graphit-iC *vs* $TiB_2$ Coated Drilling of Al-Si Alloy

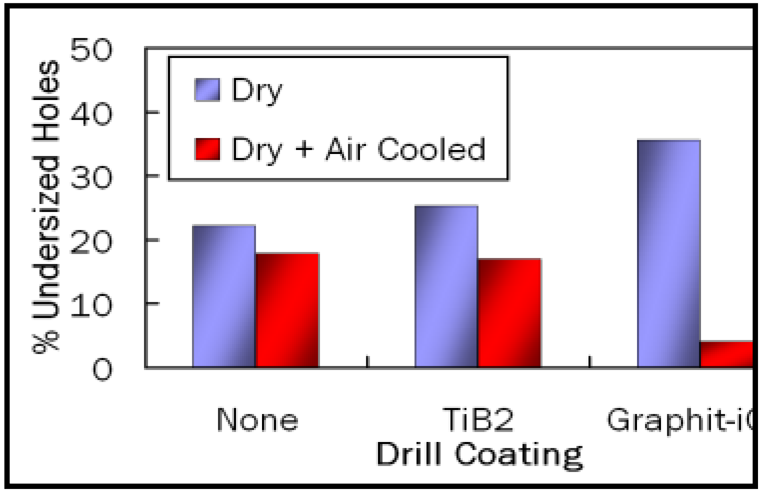



**Graphit-iC** *HSS Drill, Ø6.25mm, 70m/min, 0.127mm/rev, dry* **$TiB_2$**




No. holes to "end of life"

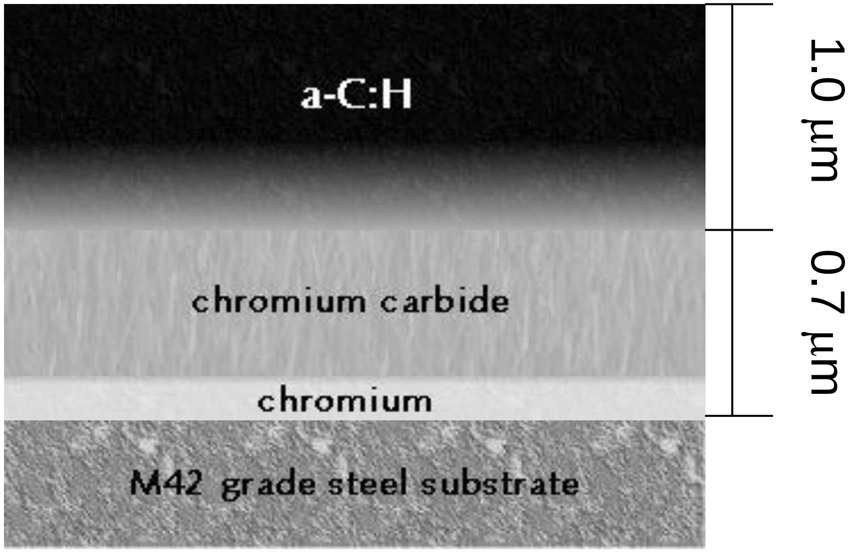



% of. holes to undersized

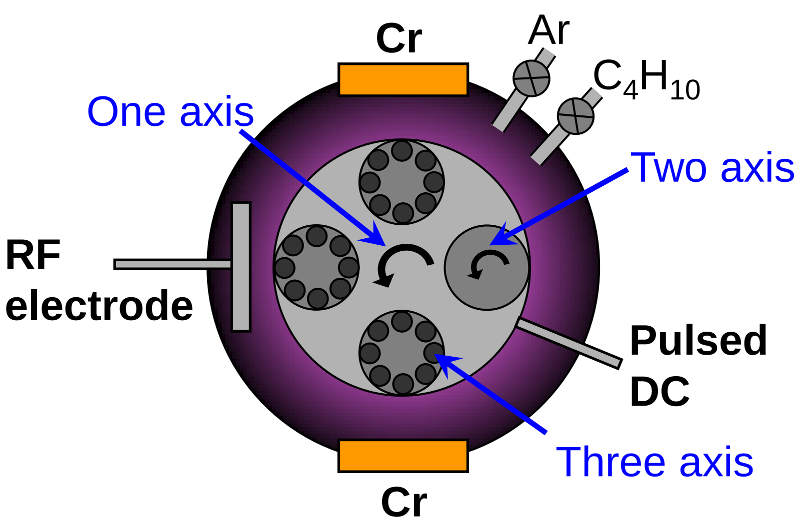
[*N Wain*]

# Dymon-iC

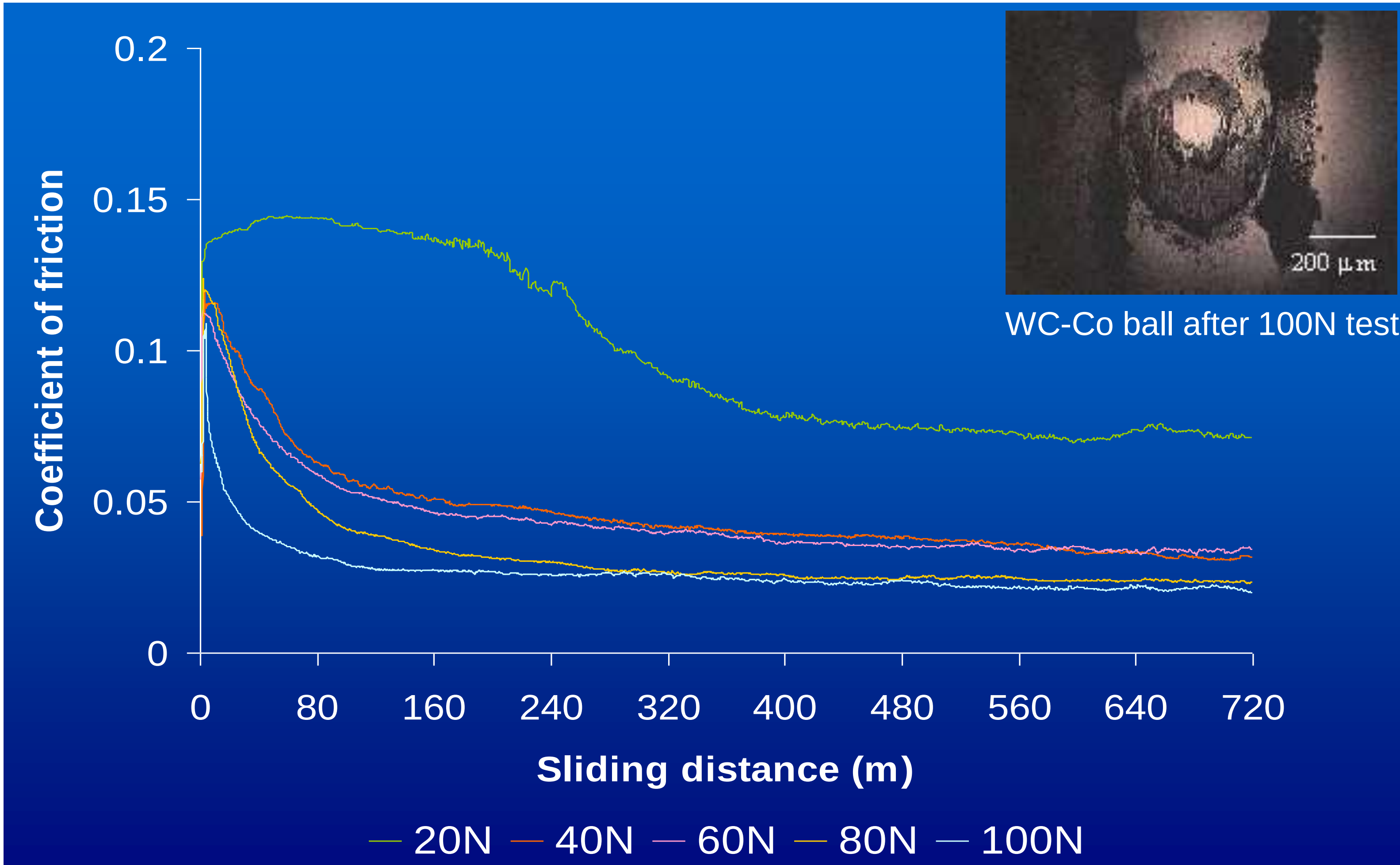
- Metal doped carbon-based coating
- Coating Characteristics
  - Thickness 2.0µm
  - Hardness >1,400 HV
  - Coefficient of friction 0.03 – 0.1
- Properties
  - Very good in vacuum
  - High load bearing capacity
- Typical Applications
  - F1 and high performance motorsport
  - Precision mechanical systems
  - Mechanical seals (steel and SiC)
  - Turning bars for paper and textile industry
  - CD stamper dies




*simulation*



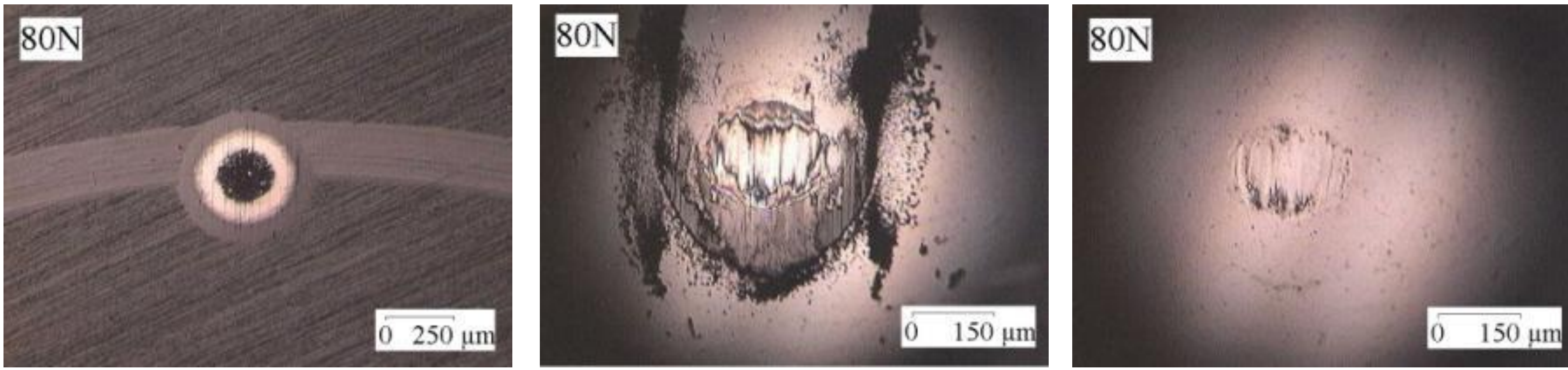
# Dymon-iC




**Evolution of the friction coefficient as a function of the sliding distance for different applied normal loads** (WC-Co 5mm ball, $200ms^{-1}$)

# Dymon-iC: Transfer Layer Mechanism

***Example of transfer layer formation***

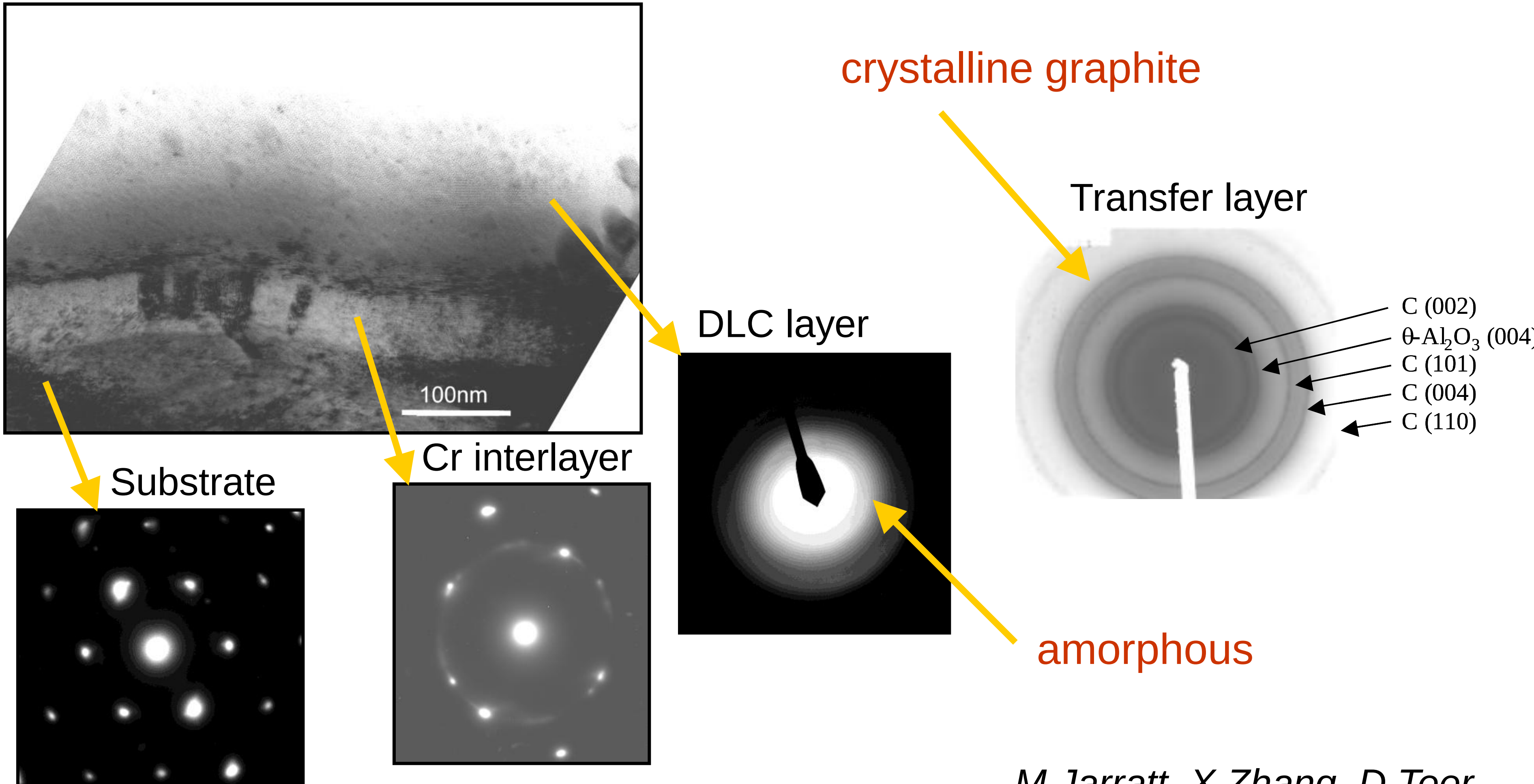



**(a)** **(b)** **(c)**

(a) wear track (b) ball surfaces and (c) wiped ball surfaces for Dymon-iC™ (on M42), after PoD with WC-6% Co ball in air, 80N, 0.2 $ms^{-1}$, 720m sliding distance

*(courtesy J. Stallard, PhD Thesis, Nottingham University, 2005)*

# Dymon-iC: Transfer Layer Mechanism



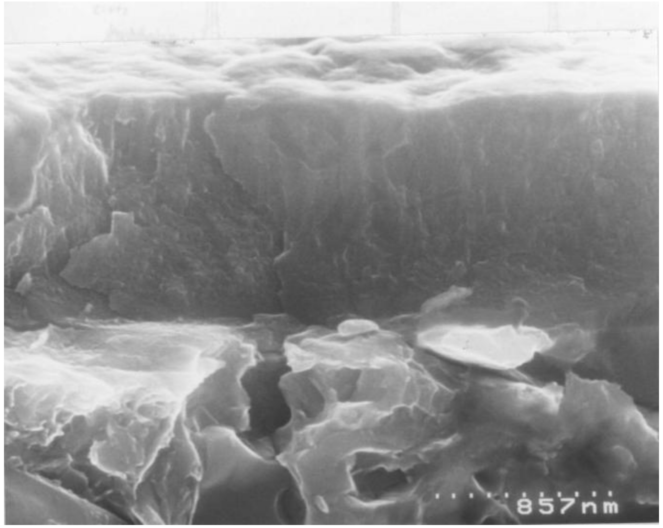

*M Jarratt, X Zhang, D Teer*

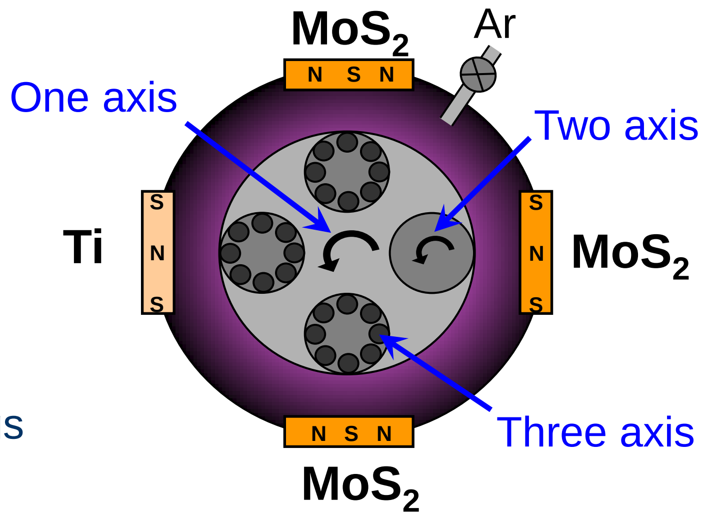
**Transmission electron microscopy, (TEM) cross-section and SAD patterns from the different coating layers and the transfer layer after a pin-on-disk test under a load of 80 N with a $\alpha$-$Al_2O_3$ ball for 60 minutes.**

# TCL MoST™

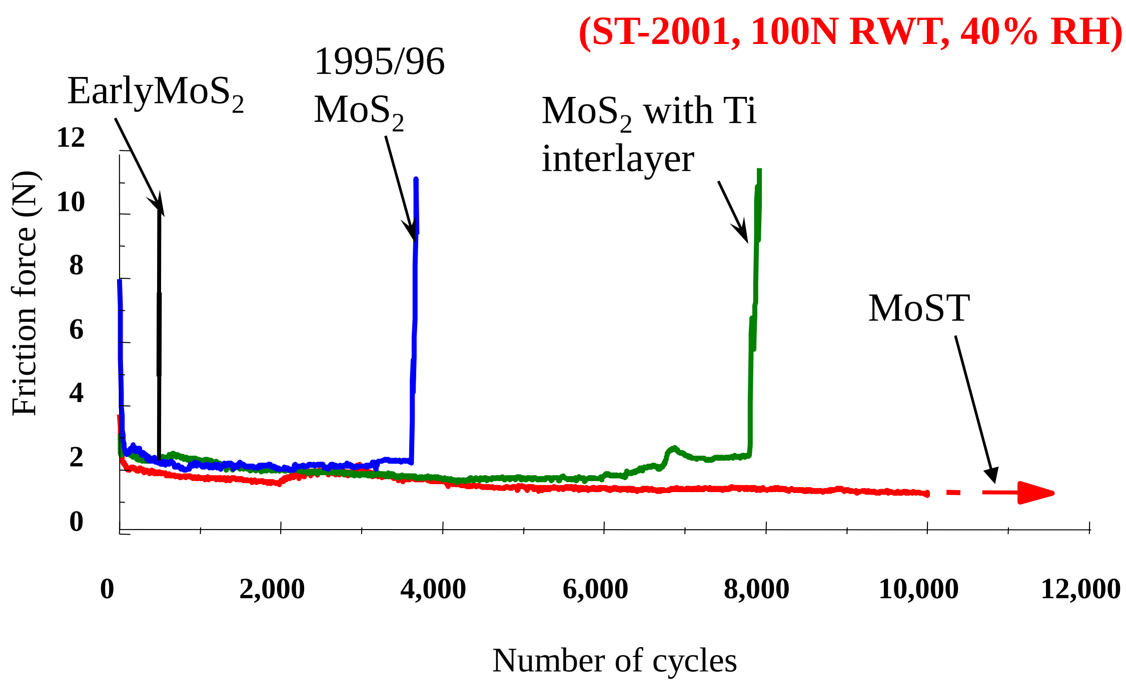
- Metal doped $MoS_2$-based coating
- Coating Characteristics
  - Thickness 1.0µm
  - Hardness 1,500 HV
  - Coefficient of friction 0.01 – 0.1
- Properties
  - Excellent in vacuum
  - High load bearing capacity
  - Comparison with $MoS_2$
    - Harder
    - More wear resistant
    - Better in humid environments
    - Same low friction
- Typical Applications
  - F1 and high performance motorsport
  - Bearing races
  - Can be used in combination with other coatings
  - Can be used as a tool coating (top coat)

*SEM (X.Zhang)*



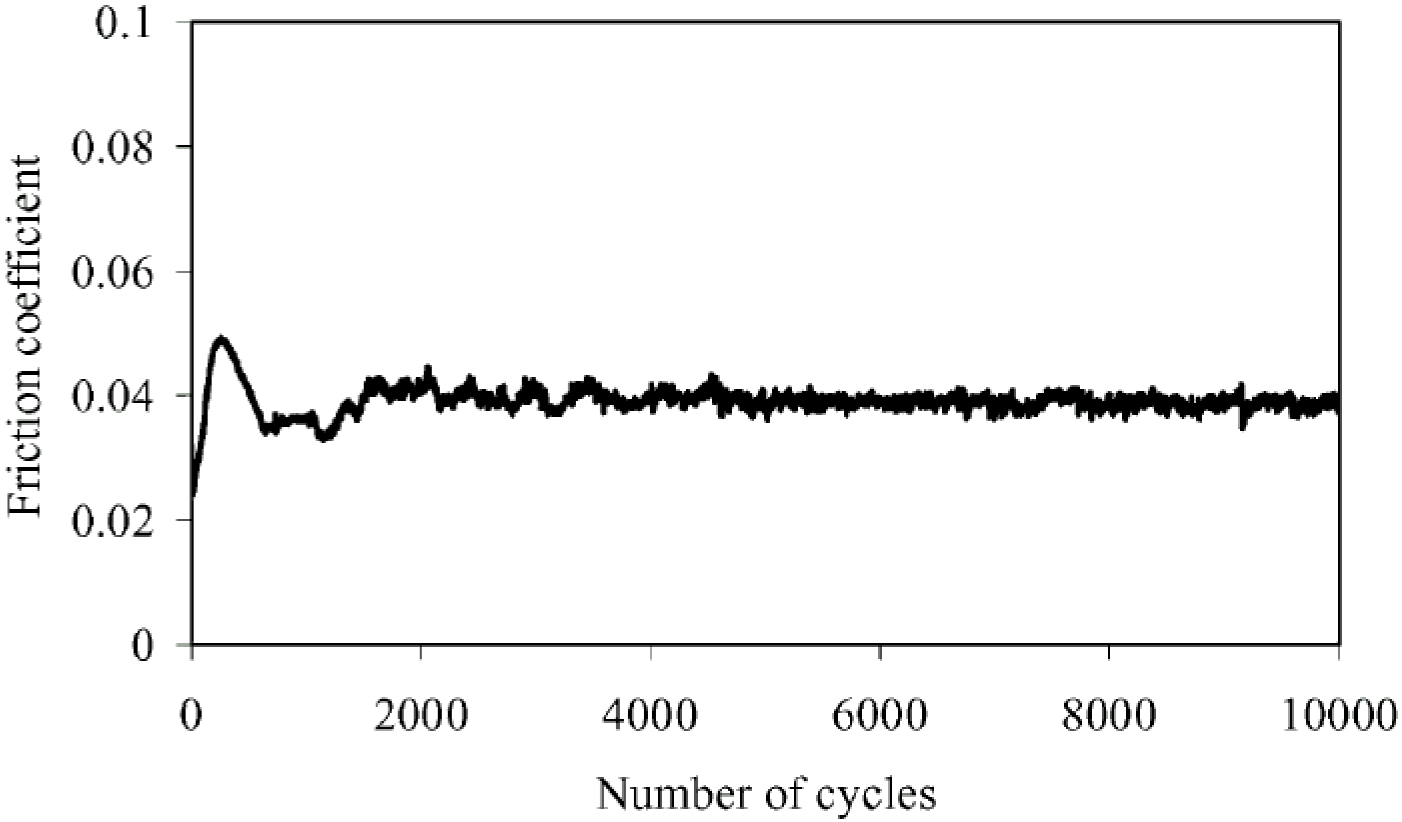
# Development of MoST




Results from 100-N reciprocating wear test on progressive $MoS_2$ and MoST coatings
*N.M. Renevier etal., Surface and Coatings Technology* **142-144** (2001) 67-77

# TCL MoST™

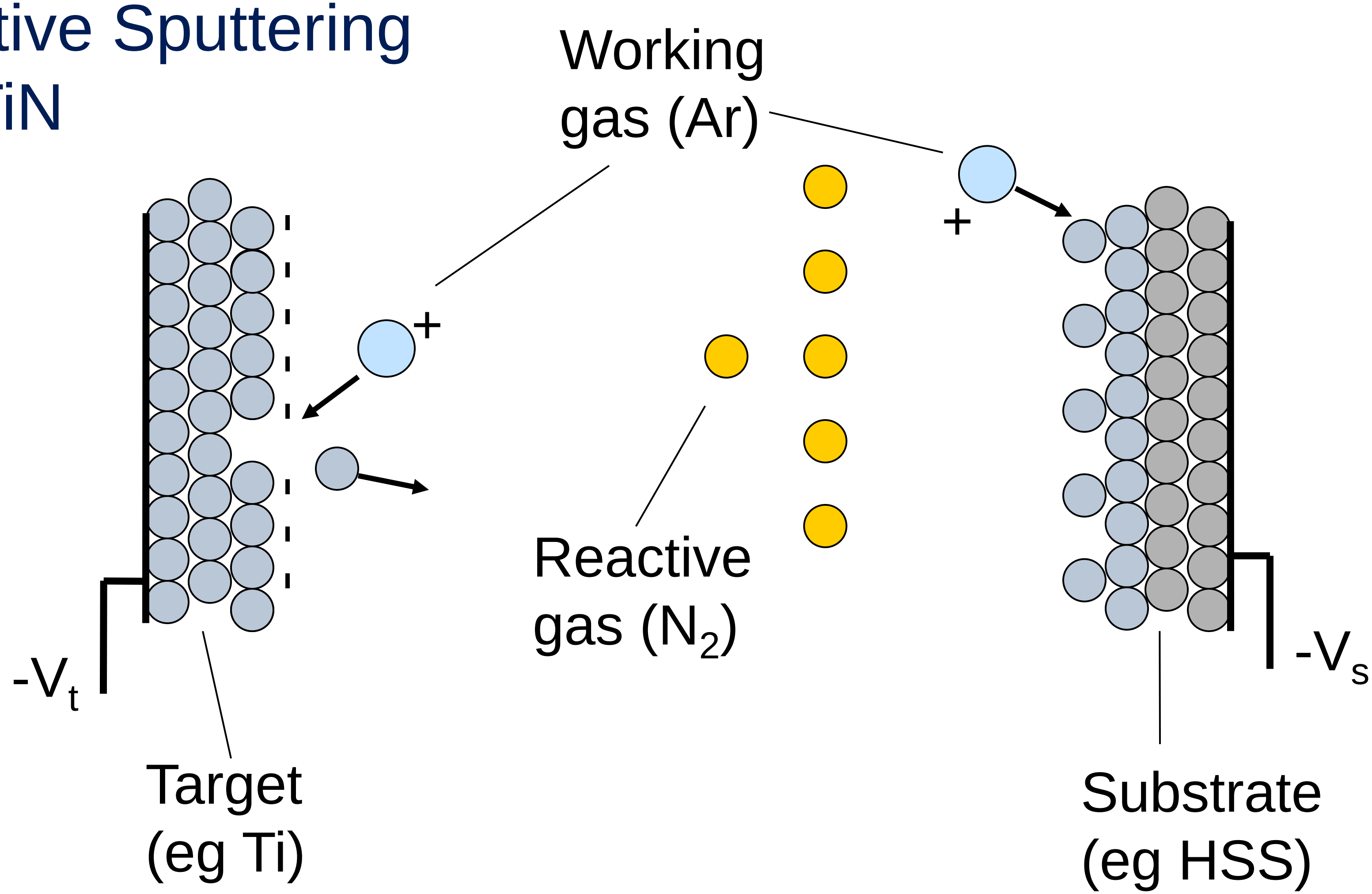
## MoST, Ambient Humidity




The 100 N reciprocating wear test at 41% humidity. Typical MoST coating, wear after test 0.50 μm (D.G. Teer, *Wear* 251 (2001) 1068–1074)

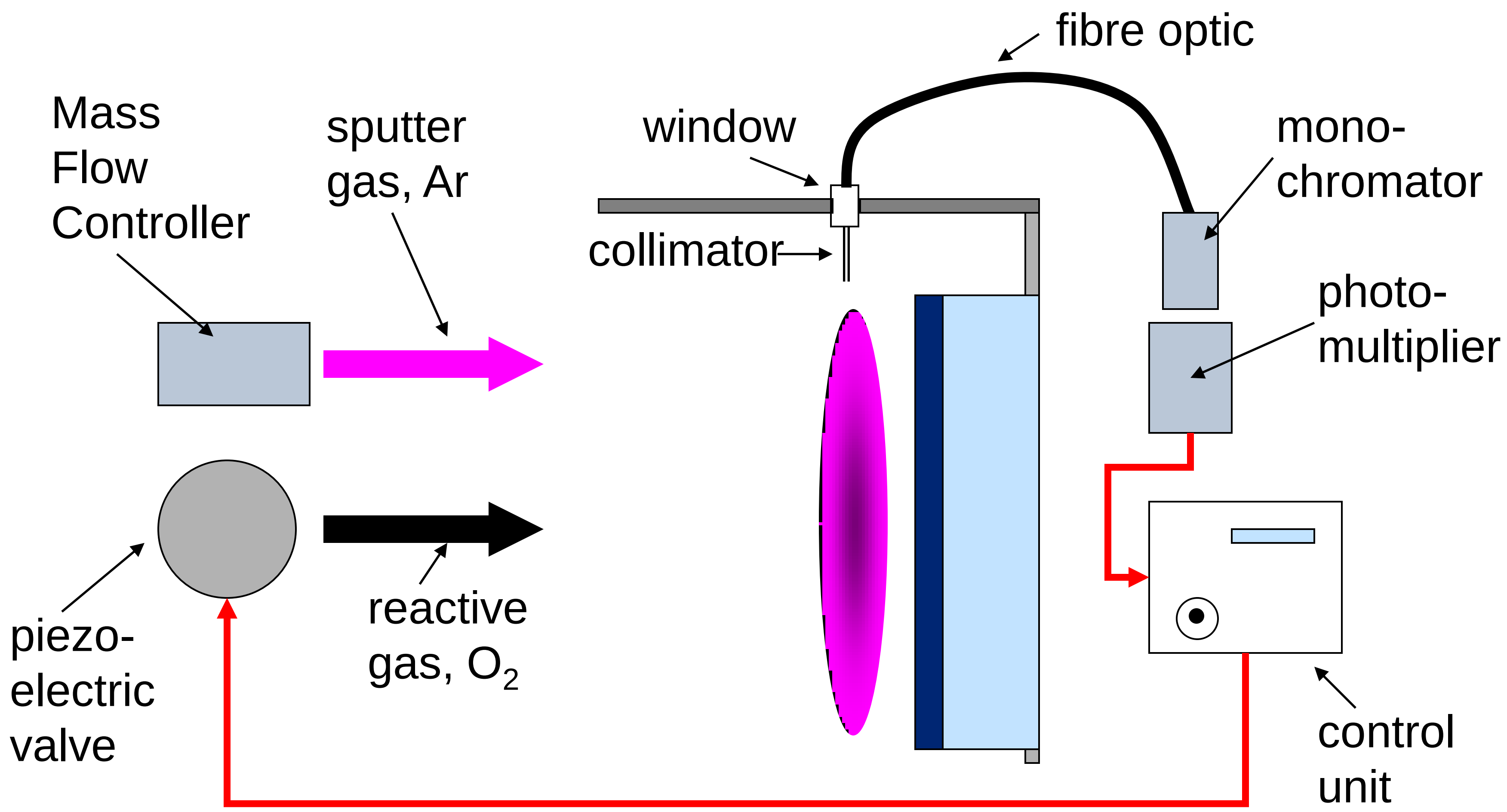
# Hard, Wear Resistant Coatings

## Reactive Sputtering e.g. TiN



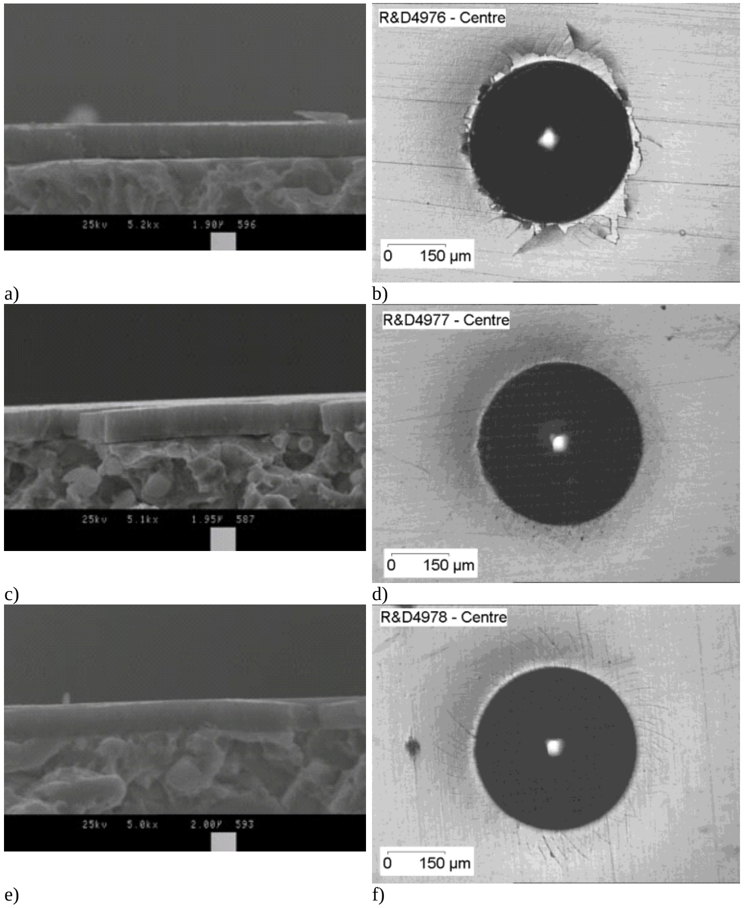
# Reactive Magnetron Sputtering

## *Optical Emission Control*



# Titanium Nitride (TiN)

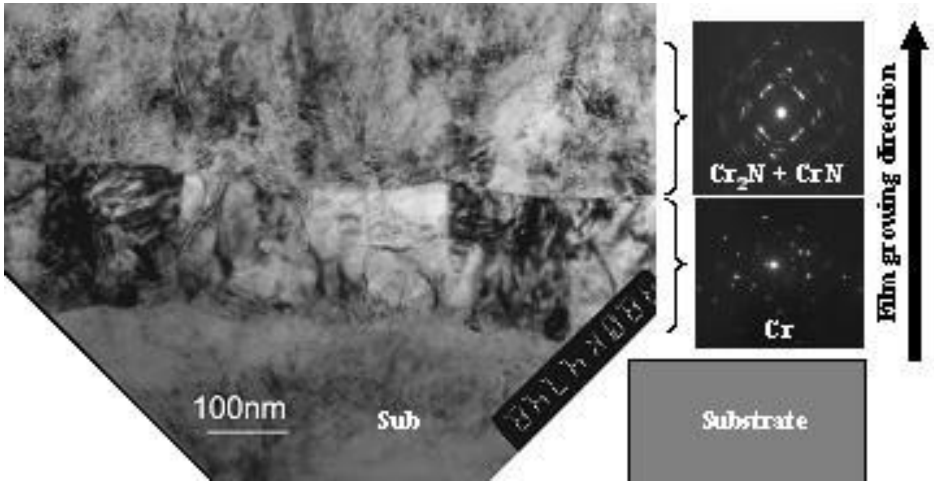
- Coating Characteristics
  - Thickness 3.0µm
  - Hardness >2,200 HV
  - Coefficient of friction 0.4
- Properties
  - Gold colour
  - Smooth coating
- Applications
  - F1 and high performance motorsport
  - Anti-galling applications
  - Abrasion resistance



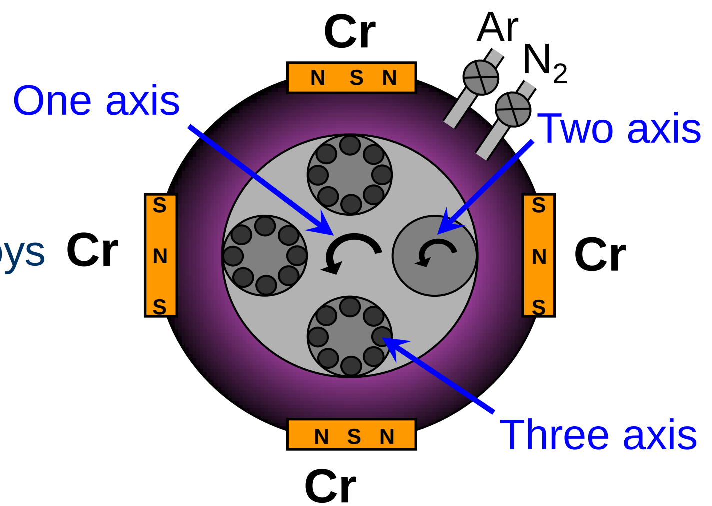

*Effect of plasma conditions on TiN coating structure and adhesion*

# Chromium Nitride (CrN)

- Coating Characteristics
  - Thickness 2.5µm
  - Hardness 2,000 HV
  - Coefficient of friction 0.5
- Properties
  - "Metallic" colour
  - Good oxidation resistance
  - Good performance in partially lubricated contacts
- Applications
  - F1 and high performance motorsport
  - Good adhesive wear properties vs non-ferrous alloys



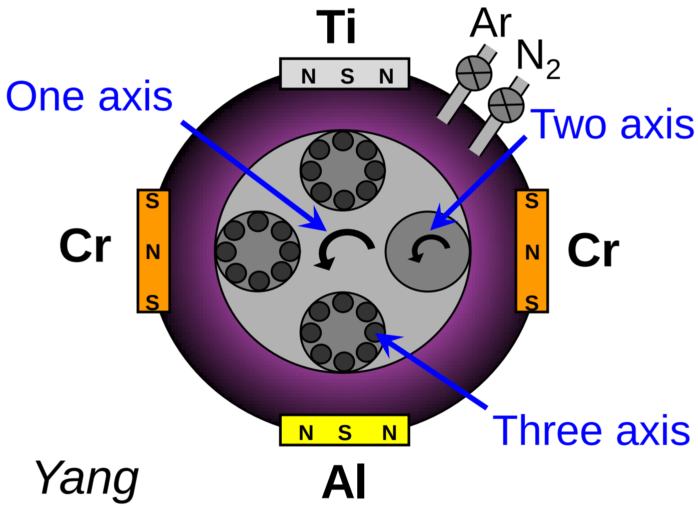

*TEM cross section at substrate interface*



# Nano-laminate, Multi-element Nitrides

- Metallic adhesion layer and graded interface, similar to CrN, TiN etc.
- Additional elements (Al, Mo, V, etc.) brought in during main coating deposition stage.
    - increased hardness, oxidation resistance, reduced CoF etc.
- Regular, repeating nm-scale layer structures.
    - Koehler-Lehoczky superlattice hardening effects, etc.

| Coating | Hardness [HV] | Friction [μ] | SWR [$m^3$/Nm] |
|---|---|---|---|
| CrN | 1500 ~ 2500 | ~ 0.6 | ~ $10^{-16}$ |
| CrAlN | ~ 3000 | ~ 0.6 | ~ $10^{-17}$ |
| CrTiN | ~ 3500 | ~ 0.7 | ~ $10^{-17}$ |
| CrTiAlN | ~ 3500 | ~ 0.7 | ~ $10^{-17}$ |
| CrMoTiAlN | ~3500 | ~ 0.35 | ~ $10^{-17}$ |

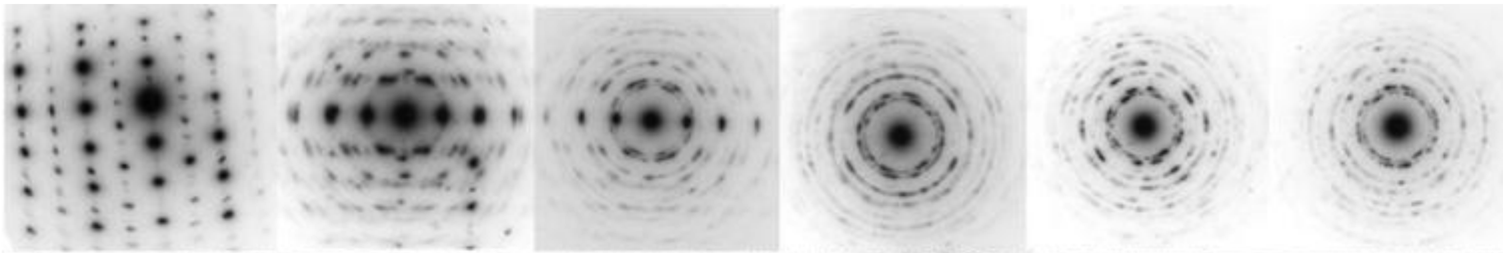



*Yang*

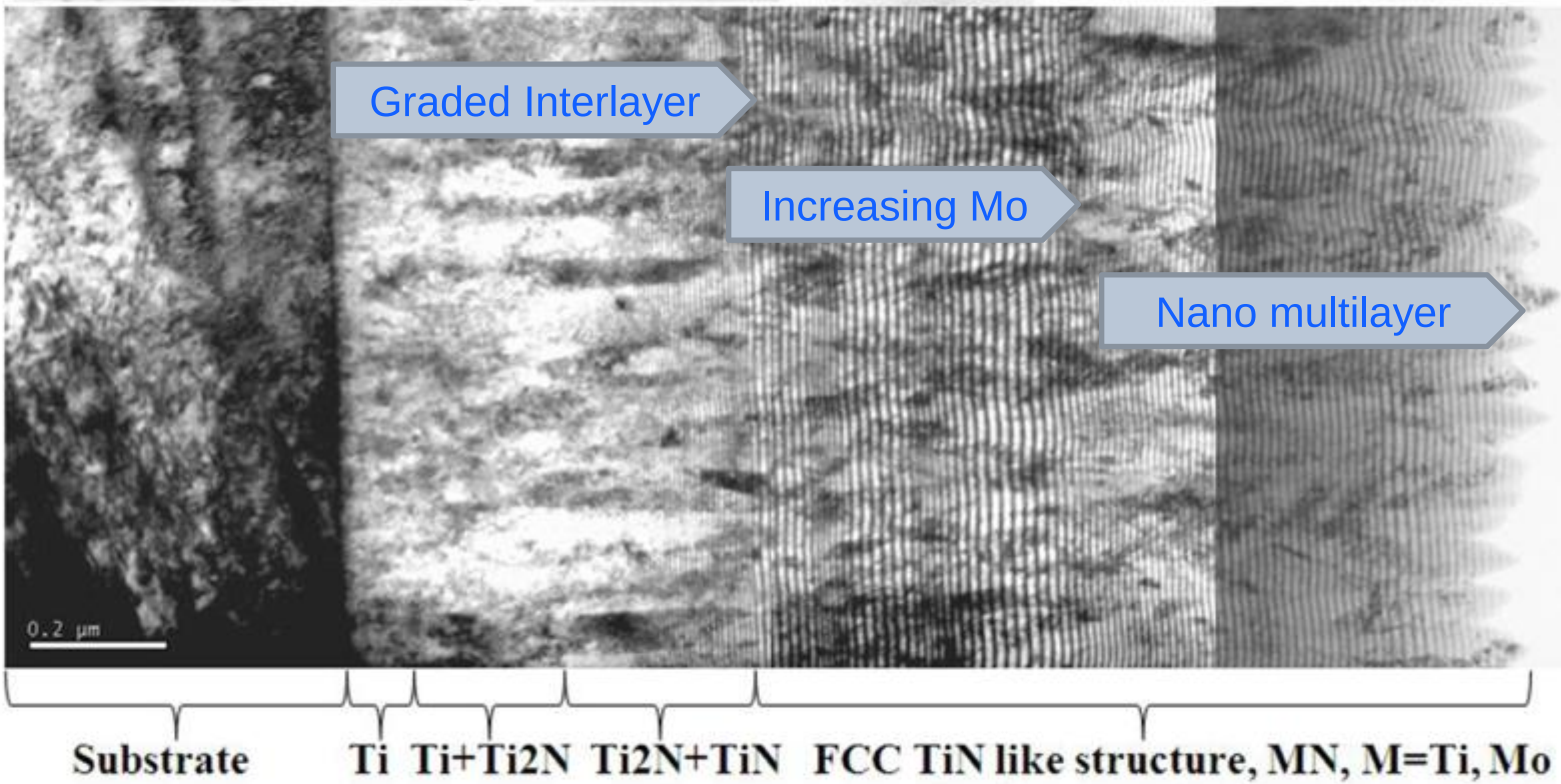
# Nanostructured High Performance PVD

Nano-multilayer TiMoN (Λ~10nm), wear resistant coating (CoF~0.45)

*Sequence of HRTEM SAD images*



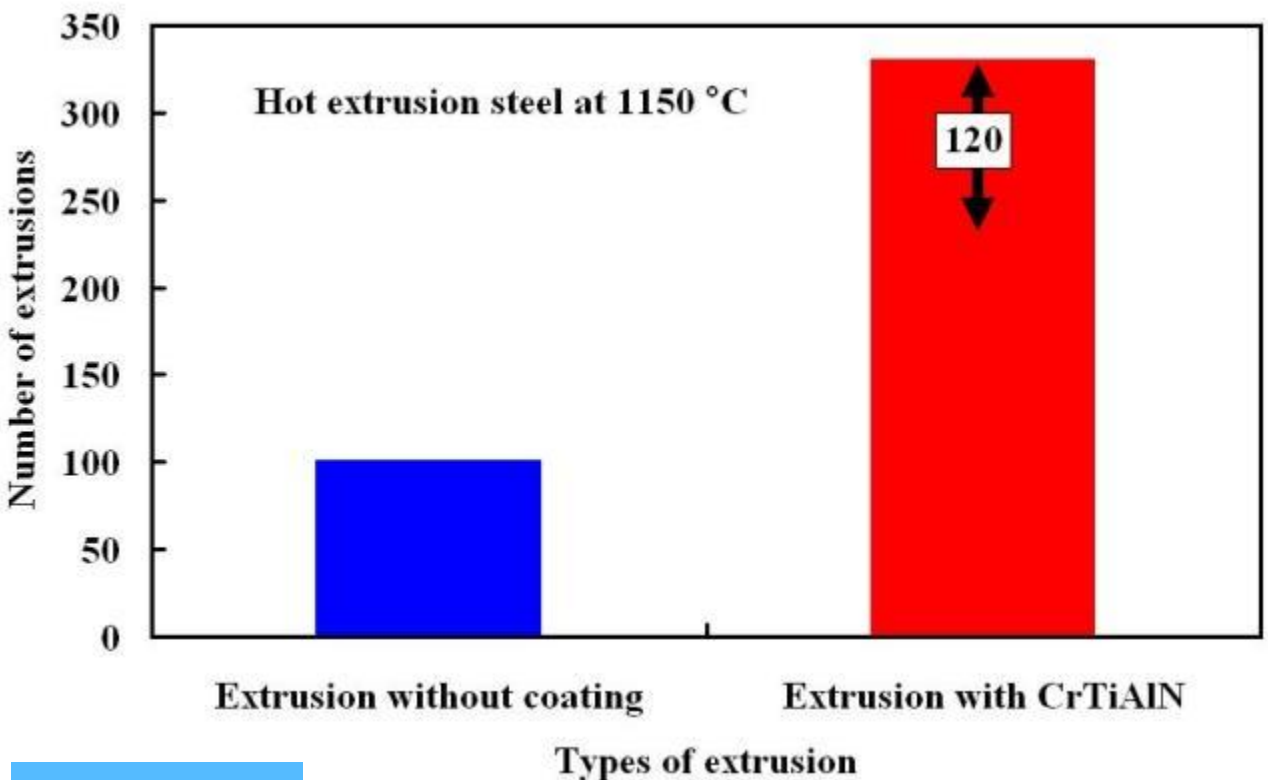
*Sequence of HRTEM cross section images*

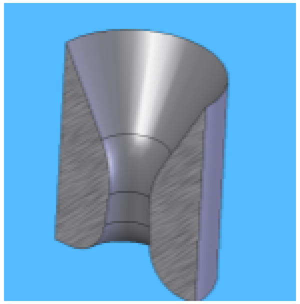



*Shicai Yang, Teer Coatings Ltd: ELMACT dissemination event, 9th Sept, 2010*

# CrTiAlN Coating on Hot Extrusion Tools

- Performance CrTiAlN coated nitrided ('tuftrided') H13 steel
- extrusion tools compared with that of the uncoated tools.
- Extrusion of steel compressor blade profiles at ~1150 ◦C.

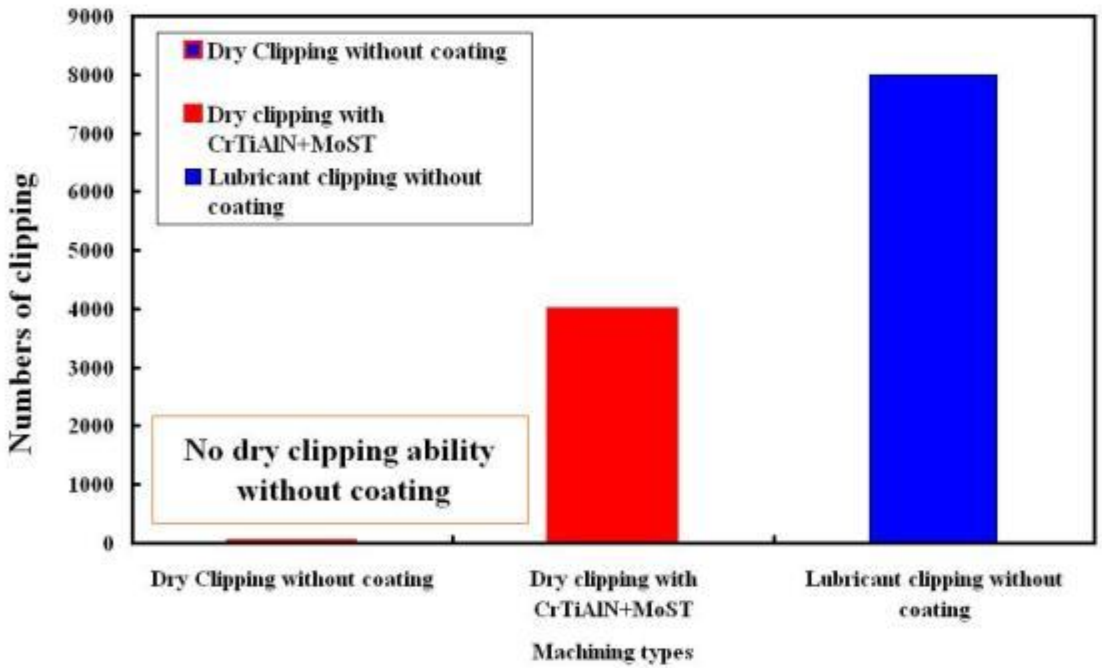


*S Yang, K E Cooke, X Li, F McIntosh & D G Teer*
*J. Phys. D: Appl. Phys. 42 (2009) 104001*
*(MAA ATEP Project: FORTUNE)*

# CrTiAlN+MoST on Cold Clipping Tools

- Combined hard coating and self lubricating coating on cold clipping tools.
- Lubricating oil is essential for the uncoated tooling.
- The coated tools have a significant “dry” life, but further work is needed

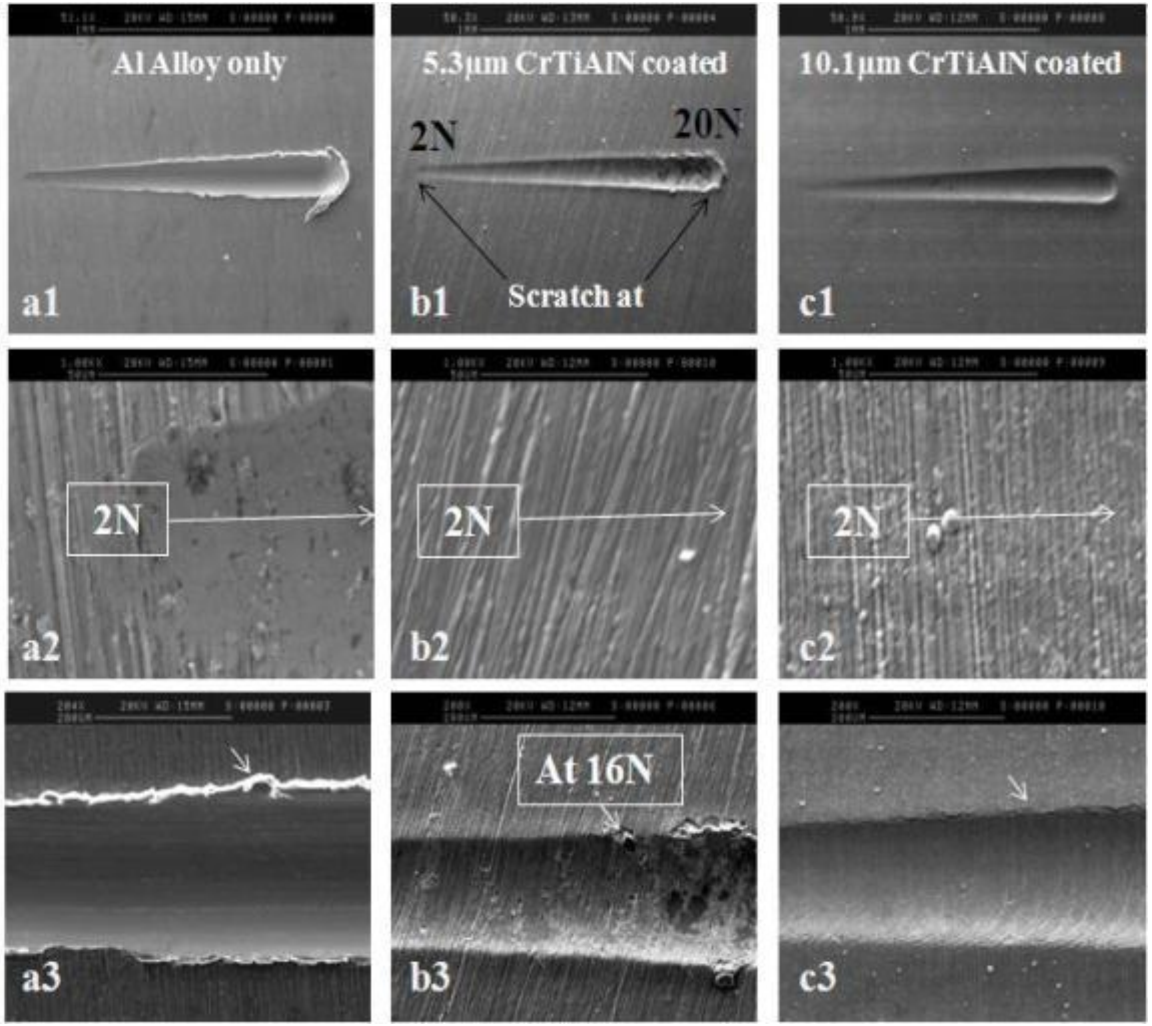



*S Yang, K E Cooke, X Li, F McIntosh & D G Teer*
*J. Phys. D: Appl.Phys. 42 (2009) 104001*
*(MAA ATEP Project: FORTUNE)*

# CrTiAlN Thick Coating on Al-alloy Substrate

- A relatively thick coating of CrTiAlN dramatically reduces plastic deformation in an Al-alloy substrate.
- Results of increasing load scratch test (2N-20N, Rockwell indenter)
- Hardness increases from 1.6GPa (uncoated) to 35.5GPa (10.1µm coating)

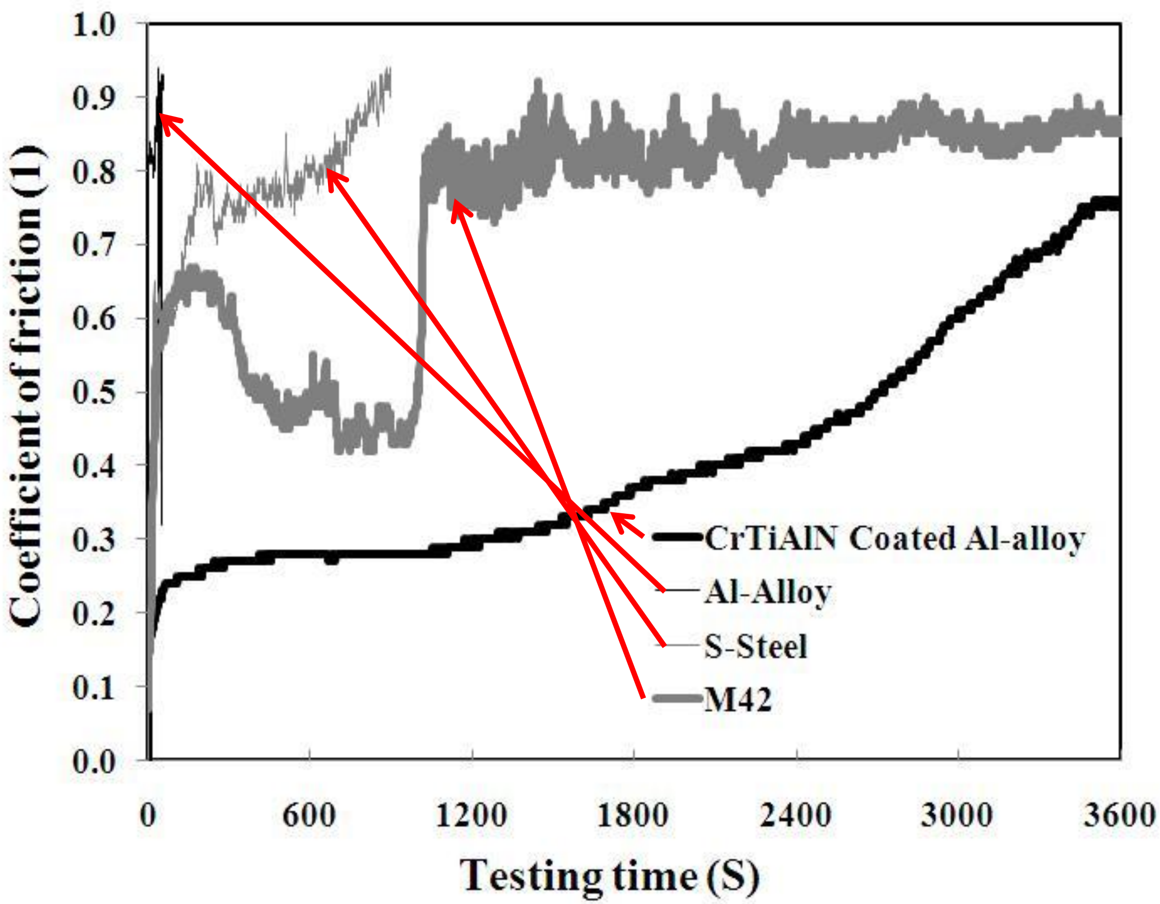
[S.*Yang*]



# CrTiAlN Thick Coating on Al-alloy Substrate

- <u>Unlubricated</u> PoD wear testing of CrTiAlN (5.3µm) coated Al-alloy substrate, compared to uncoated Al-alloy, stainless steel and M42 tool steel.
- Ø5mm WC-Co ball, 2N load, 200mms$^{-1}$.
- Coated Al-alloy performs significantly better than uncoated alloy steel.

[S.*Yang*]



# PVD Coating of Aluminium Alloys

- Magnetron sputtering does not need high process temperatures:
  - Thermally sensitive materials, polymers, bearing steels, high strength Al-alloys, etc. can be coated.
  - Process temperatures can be maintained <200°C, and even <150 ° C, if required.
  - Others have coated e.g. Al 7075-T6 with TiN, at 450°C, and used post-coating heat treatment to restore mechanical properties.
    - R H Oskouei, R N Ibrahim, Surface & Coatings Technology 205 (2011) 3967–3973
- Coatings can improve the wear resistance, but :
  - For thin coatings, if the loads are too high, wear will increase.
    - M H Staia et al, Surface Engineering 20 (2004) 128-134

# Conclusions: PVD Coatings for Aerospace

- Miba Coating Group is a leader in industrial PVD technology.
  - Highly automated, semi-continuous processing is possible.
- Teer Coatings Limited provides a wide range of coatings, including self-lubricating, wear and abrasion resistant films.
  - Various substrate geometries accommodated – including powders.
- Nano-scale multilayers can be integrated into state of the art, muti-component nitrides
  - Wear resistance, high toughness, thermal endurance, etc.
- Coatings can reduce friction, parasitic losses, etc.
- Coatings can increase the durability and performance of lightweight alloys.
- Coatings can improve the performance of cutting and forming tools.
- These are only examples – Miba Coating Group is your ideal partner for PVD-based coating technology.

# Questions.....?

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