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Water droplet erosion

Figure 1: Water droplet erosion: samples located in a high speed rotating arm impact water droplets at speeds in excess of 300 m/s causing erosive wear.

Machine capability
Maximum design speed: 9,500 rpm 500 m/s.
Nozzle sizes 0.1 - 2.0 mm.

Sample specification
Two samples tested simultaneously.
24.0 x 8.0 x 3.3 mm.

Evaluation
Mass loss measurements.
3D optical microscopy.
SEM with EDX, FIB-SEM.

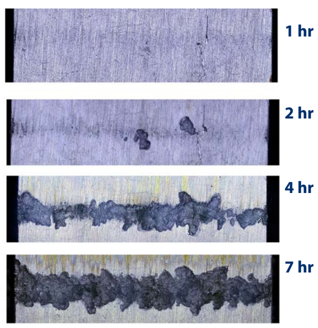

Figure 2: Sequential development of wear scars on hardened steel with incremental exposure.

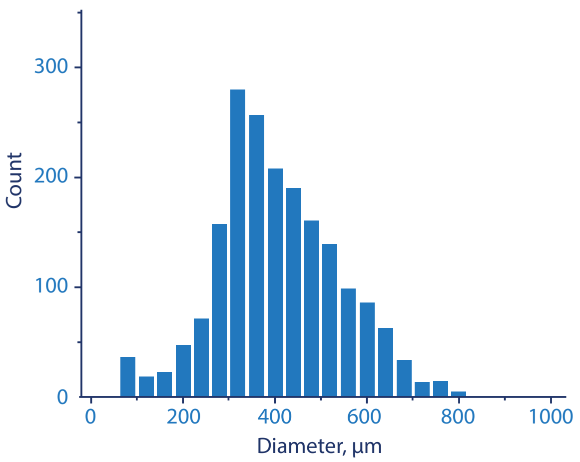

Figure 3: Size distribution of water droplets.

Description

NPL's water droplet erosion test rig is used to investigate the damage resistance of surface finishes when exposed to impact from high velocity water droplets. Two samples are placed at opposite ends of a rotating arm, such that each sample collides with the water jet under a vacuum, as per the ASTM G73 - 10 and ISO 19392 - 2 standards. The test system can generate water droplets of varying sizes and velocities, simulating real-world conditions for wind turbine blades, aerospace components and steam turbines exposed to high-velocity rain. This provides valuable insights into surface durability under different impact conditions. Samples are removed after a set number of impacts, with mass loss recorded and wear scar imaged before further testing.

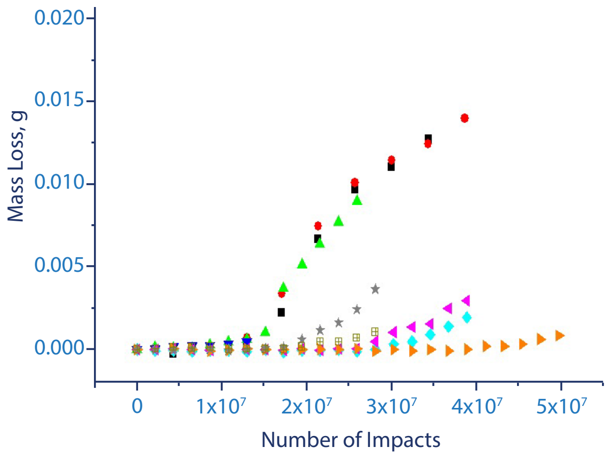

Figure 4: Plot of mass loss vs number of impacts. Black, red and green are repeat experiments with uncoated samples, the remainder have various coatings.

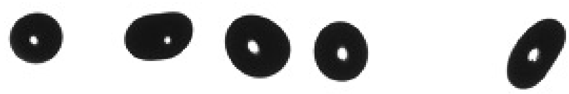

Figure 5: Images of water droplets.

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Scratch tester

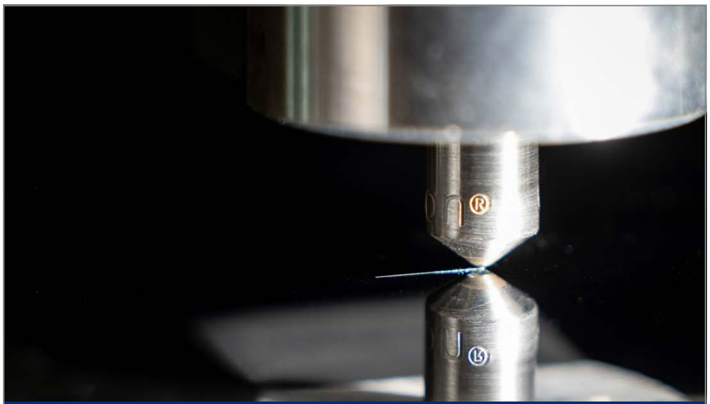

Figure 1: Scratch resistance evaluation: a diamond indenter traverses the sample surface with a continuously increasing load causing abrasive wear and plastic deformation.

Machine capability
Applied normal load range: 1 - 250 N.
Type of loading: constant or linearly variable.
Type of motion: single or repetitive unidirectional, reciprocating motion.
Friction force measurement range: ±80 N.
Sliding speed: 0.1 - 45 mm/s.
Scratch length: 100 mm maximum in a single direction.
Indenter: Rockwell with nominal radius of 200 µm (other geometries are available).
Acoustic emission measurement.

Sample specification
Typical dimensions: 50 x 50 x 3 mm (other geometries can be accommodated).

Evaluation
In situ wear measurements.
Friction force: applied load vs displacement graphs.
Acoustic emission: applied load vs displacement graphs.
Wear scar profilometry.
3D optical imaging and SEM.

Description

The NPL scratch tester is used to determine the resilience of engineered surfaces, including coatings and surface treatments. Unidirectional scratches are made using diamond indenters as per the ASTM D7027 and G171 standards. The indenter depth, friction force and acoustic emission are measured and recorded during each scratch, and are then correlated with the applied load and sliding distance. This provides a detailed insight into the mechanical response of the surfaces to damage from a well-characterised probe. The in situ wear and friction measurements are normally complemented by post-test 3D optical imaging. The test system is fully computer controlled and is readily adapted to perform dry and lubricated sliding experiments to evaluate the friction and wear of material couples manufactured from coupons or sections of production parts.

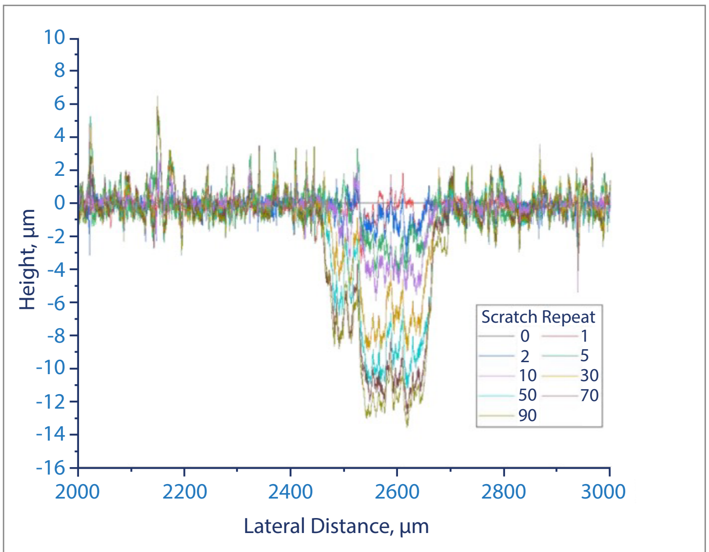

Figure 2: Surface profile measurements after incremental scratching. [1]

[1] M Gee, T Kamps, J Nunn and P Woolliams. Project IND1705 Multifunctional ultrafast microprobes for on-the-machine measurements, EMPIR, Good Practise Guide – In-situ wear damage measurement using fast microprobes with integrated feed-unit. National Physical Laboratory. 2021. Good_Practice_Guide_No_6_In-situ_wear_damage_measurement_using_fast_microprobes_with_integrated_feed-unit.pdf

Figure 3: Typical scratch on DLC-coated steel sample showing complete failure of coating at a critical load.

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Pin-on-disc

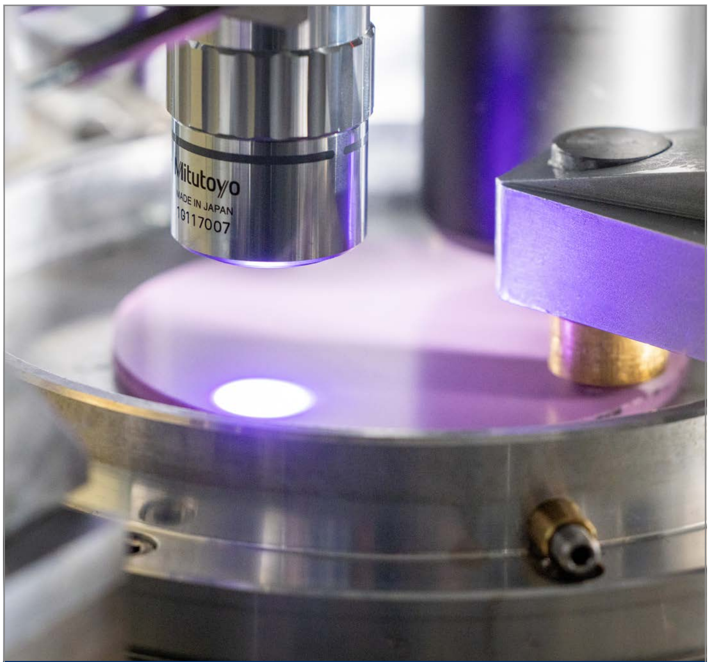

Figure 1: Pin-on-disc testing: NPL's integrated pin-on-disc tribometer equipped with 2D and 3D machine vision technology can identify wear mechanisms in near real-time.

Description

The pin-on-disc test system is used to investigate the way a material's surface responds to a unidirectional sliding tribological contact. This machine measures the friction and wear of contact between a stationary sample – such as a fixed ball – and the flat side of a rotating disc as per ASTM G99. Tests can be carried out under both dry and lubricated conditions. The system is fitted with several sensors to monitor the wear process as it is taking place, including a 2D linescan, a 3D multipoint probe and a linear variable differential transformer (LVDT). The 2D linescan continuously images the wear scar in situ, classifying the wear mechanism using a convolutional neural network in near real-time. The multipoint probe measures the topography of the wear track in real time, and the LVDT measures the total wear of the pin at the disc. The machine can be modified to become a test rig for thrust bearings.

Machine capability
Contact geometries: point contact, area contact and thrust bearing.
Optional modules: fluid property sensor, interferometer, charge detector and convolutional neural network.
Speed: 2 - 1,450 rpm (corresponding to 0.01 - 7.50 m/s for a 100 mm wear track diameter).
Load: 0 - 450 N.
Additional capability: thrust bearing rig.

Sample specification
Size: 75 - 130 mm diameter, typically 3 mm thick.
Sample nature: coated or bulk material.

Evaluation
Continuous acquisition of images and data, including friction, wear scar height and depth.
Real-time correlation of friction with surface topography evolution.
Near real-time wear mechanism classification using a convoluted neural network.

This measurement capability is explained in greater detail in this open access article (including videos):

M Gee, T Kamps, P Woolliams, A new paradigm in uniaxial wear testing for ceramics and ceramic coatings, International Journal of Refractory Metals and Hard Materials 130 (2025) 107127

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Reciprocating tribometer

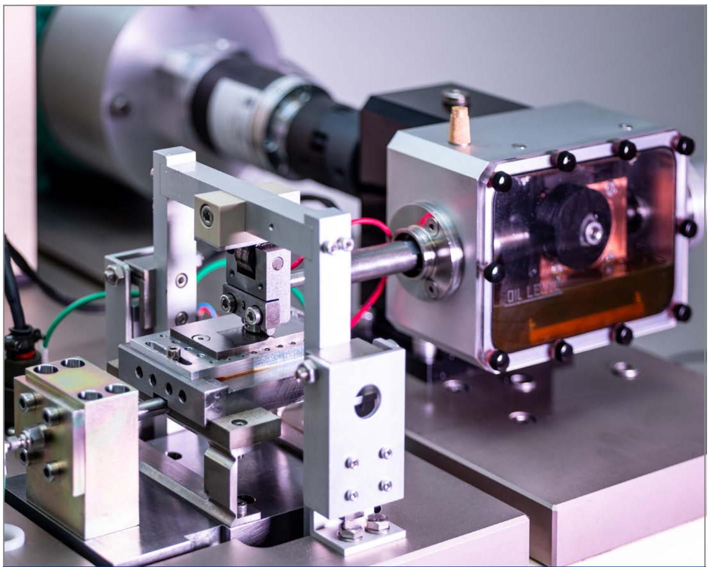

Figure 1: Reciprocating sliding: TE-77 tribometer equipped with spatially resolved friction measurement is capable of dry and lubricated tests up to 600 °C.

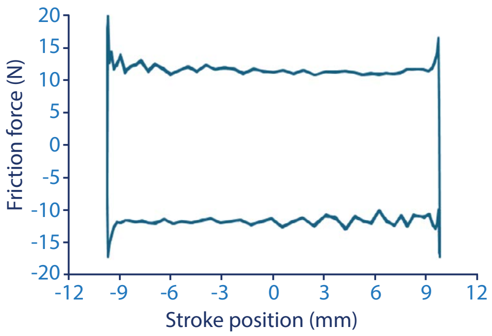

Figure 2: Spatially resolved friction force, for a lubricated reciprocating line contact.

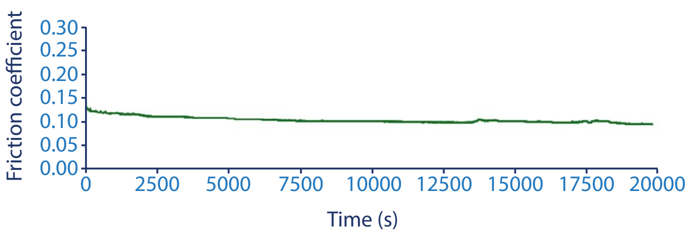

Figure 3: Root mean squared average friction against test time for a lubricated reciprocating line contact.

Description

The TE-77 reciprocating tribometer (manufactured by Phoenix Tribology Ltd.) is used to measure the friction and/or wear of material couples following the ASTM G133 standard. Friction is measured using a high bandwidth piezoelectric transducer and resolved against position. Wear is measured in situ by a capacitance probe that tracks the change in height of the reciprocating assembly as the test progresses. A small electric potential can be applied across the contact of the stationary sample and the reciprocating counterface. This serves as a qualitative measure of coating performance and provides insight into tribo and lubricant film formation and removal. The machine can be adapted for different contact geometries, including point, line and area contacts, and can also be configured for sliding rolling contacts. It can perform both dry and lubricated tests at ambient and elevated temperatures.

Machine capability
Details of contacts: point, line, area. Can be purely sliding or slide-roll (area contacts).
Stroke: 0.4 - 25 mm.
Force range: 5 N to 1 kN.
Stroke frequency: 2 - 50 Hz, or 0.04 - 1.00 Hz if 50:1 gearbox fitted.
Temperature range: ambient to 650 °C.
Contact potential: 50 mV DC signal.
Optional modules: wear, fluid property sensor, lubricant dosing.
Programmable speed, load and temperature during testing.

Sample specification
Typical geometry 38 x 58 x 4 mm – custom samples can be secured with M4 countersunk screws.

Evaluation
Measured parameters: load, friction (rms), friction, contact potential, stroke position, temperature, frequency, number of cycles.
3D optical microscopy/ profilometry of wear scar.

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Solid particle erosion

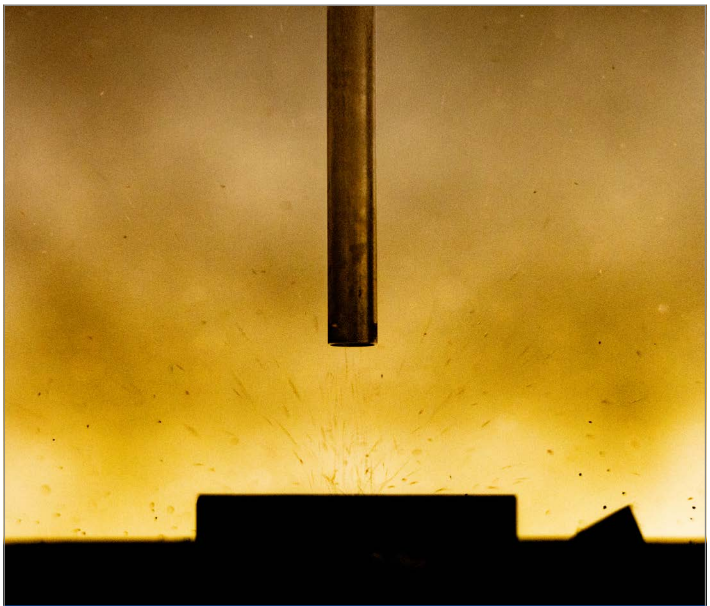

Figure 1: Gas-borne particulate erosion: particles are accelerated in a high velocity gas jet to impact on a test surface causing erosion.

Description

NPL's solid particle erosion capability consists of a TE68 solid particle erosion machine and an in-house high temperature solid particle erosion (HTPSE) rig. These systems are used to investigate the resistance of surfaces to damage from solid particle erosion following ASTM G76 and ASTM G211 - 14 2020 standards. Both systems use particles, delivered through a steel nozzle by a high velocity gas stream, to impact the sample surface. Measurements of mass loss are normally made after exposure, but the HTSPE rig also has in situ mass measurement capability. The mass loss measurements are normally combined with 3D optical imaging and profilometry to determine the magnitude and mechanism of damage to the surfaces.

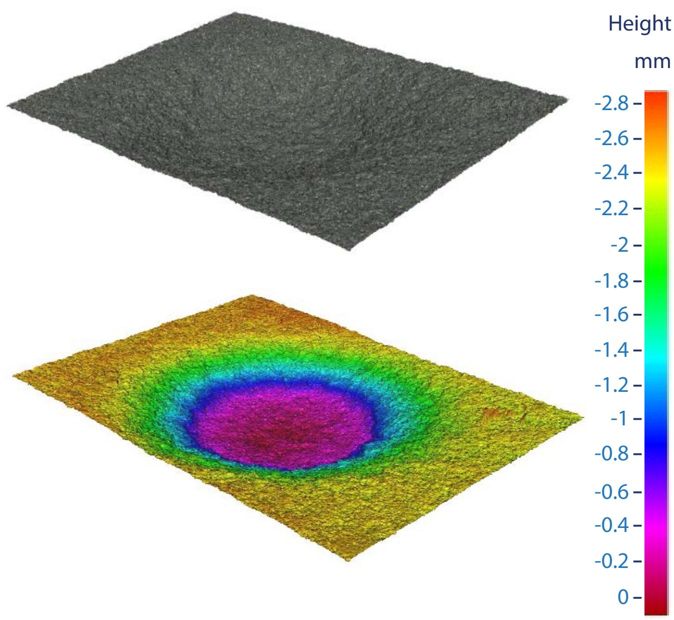

Figure 2: Wear scar image.

Machine capability		
	TE68	**HTSPE**
Particle velocity	25 - 150 m/s.	Up to 300 m/s.
Temperature	Ambient (20 °C).	Up to 900 °C.
Angle of incidence	20 - 90 degrees.	45 and 90 degrees.
Mass loss measurement	Ex situ incremental.	In situ incremental.
Erodent	Silica free bulk powders.	Silica free bulk powders.

Sample specification
Sample size: typically 40 x 20 x 2 mm (max size 50 x 50 mm).

Evaluation
Mass loss.
3D microscopy of wear.
SEM.