

Advanced tribology testing: precision measurement for surface performance

Evaluating friction, wear and lubrication
in demanding environments



What is tribology and why is it necessary?

It is crucial for manufacturers to have a clear insight into the way that materials react to external factors because, if they don't perform as expected, failures can occur and the end products will have shorter lifetimes. Mechanical wear, along with exposure to water, dust, chemicals and extreme temperatures, can all alter a material's surface, but a thorough understanding of these effects can help in the development and selection of fit-for-purpose materials.

This is where the field of tribology comes in. Tribology refers to the study of how surfaces interact when they move against each other, considering phenomena such as friction, lubrication and wear.

More than one mode of wear frequently occurs at the same time, making interpretation of results difficult. Different tests are therefore needed to simulate the different mechanisms at play and, in many cases, forensic examination of the worn surfaces helps to determine the exact causes of damage.

Tests are often tailored to specific applications because of the need to address complex operating regimes. Mass loss is typically used to assess wear, but analysis may also include 3D microscopy, image subtraction, scanning electron microscopy and failure examination, including sample preparation and polishing where necessary. The application of these advanced tribology techniques can enable success and growth in many sectors, such as energy and utilities, oil and gas, environment, aerospace, automotive, manufacturing, the life sciences, defence and security, agriTech, IT and telecommunications.

The National Physical Laboratory (NPL) – experts in surface engineering

We provide expert mechanical testing, non-destructive evaluation, thermal analysis and modelling to clarify requirements, interpret results and solve challenges with respect to the performance of both bulk surfaces and specialised coatings. Our independent analysis helps customers to identify the root causes of material or structural failures, allowing them to evaluate materials for better design, improved performance and higher quality.

NPL's rigorous tests adhere to industry standards and, for complex interfaces, we provide a comprehensive approach by integrating surface and mechanical testing. Our real-time data acquisition methods improve resolution while reducing costs, moving beyond traditional periodic measurements, and we apply machine learning to classify wear mechanisms dynamically, optimising test parameters for greater efficiency. We also offer tailored testing and consultancy, including mechanical property evaluation, sliding wear and friction testing, abrasion and erosion testing, and nanomechanical analysis.

Abrasion testing

Abrasion testing evaluates the wear and degradation of engineered surfaces caused by continuous mechanical contact with another material, which can lead to friction, scraping or rubbing. It's conducted by either moving an abrasive medium across the surface or reciprocating the surface against a fixed abrasive material.

Dry sand rubber wheel test (ASTM G65)

Simulates moderate abrasion. An NPL modification enables tests to be carried out with other abrasives and under wet or dry conditions.

High stress abrasion resistance test (ASTM B611)

Simulates very severe abrasion. Developed for hard metals or cemented carbides.

Micro-scale abrasion test

Simulates abrasion by fine particles under light load conditions. Measures the wear resistance of thin coatings.

Erosion testing

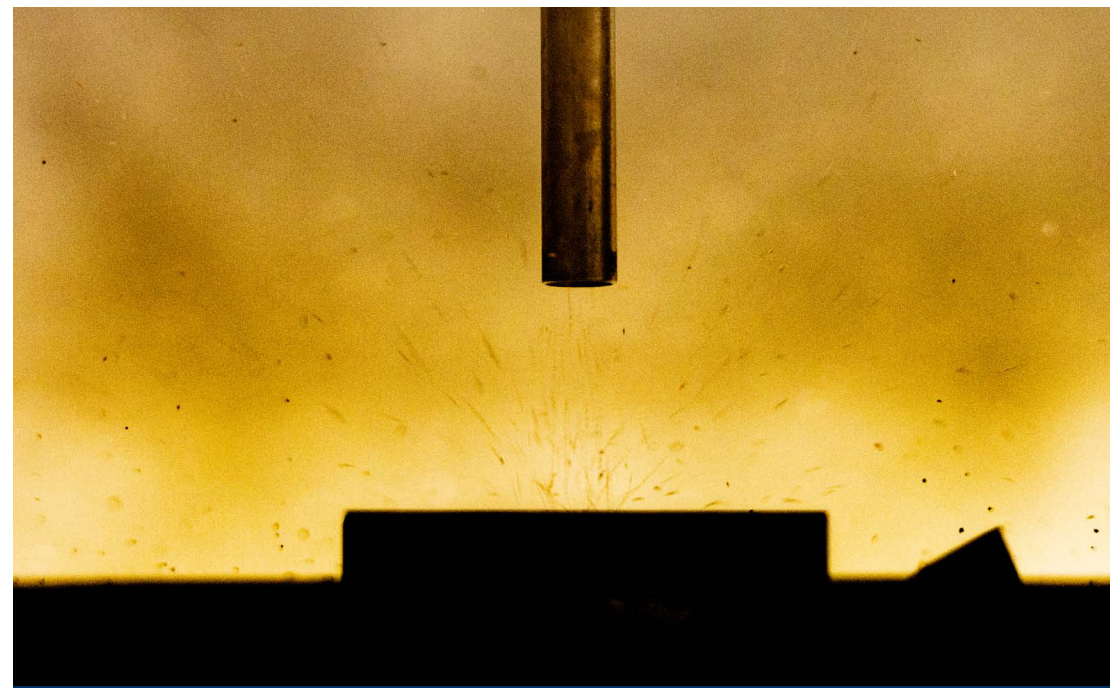
Erosion testing involves the analysis of damage occurring when a small object – such as a grain of sand, a metal or oxide particle, or a droplet of water – strikes a surface and removes material. It is implemented by either accelerating the particle onto the surface, or moving the surface onto the particle.

Gas-borne particulate erosion test (ASTM G76)

Evaluates material erosion using erodants at velocities of up to 75 m/s. Measures mass loss over time, calculates erosion rates and analyses wear mechanisms through optical, scanning electron and 3D microscopy.

Solid particle erosion test (ASTM G76-18 and ASTM G211-14(2020))

Evaluates material erosion at temperatures of up to 600 °C and velocities of up to 300 m/s. Enables real-time mass and wear volume measurements without cooling interruptions, with post-test analysis using optical, scanning electron and 3D microscopy. NPL's solid particle erosion capability consists of a TE68 solid particle erosion machine and an in-house high temperature solid particle erosion (HTSPE) rig. Particles are delivered in a high velocity gas stream through a steel nozzle against the sample surface. Measurements of mass loss are normally made after exposure, but the HTSPE rig also has in situ mass measurement capability. Mass loss measurements are combined with 3D optical imaging and profilometry to determine damage.



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



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.

Water droplet erosion test (ASTM G73-10, ISO/TS 19392-2)

Evaluates damage from water droplets on fast-moving surfaces at speeds of up to 300 m/s for steam turbines and 150 m/s for wind turbines. Mass loss is measured throughout, with optical and scanning electron microscopy used to track damage progression. NPL's water droplet erosion test rig is used to investigate the resistance of surface finishes to damage when exposed to impact from high velocity water droplets. Two samples are placed at opposite ends of a rotating arm so that each sample collides with the water jet under vacuum. Samples are removed after a given number of impacts, the mass loss recorded and wear scar imaged prior to further testing.

Scratch resistance and hardness evaluation (ASTM D7027 and G171)

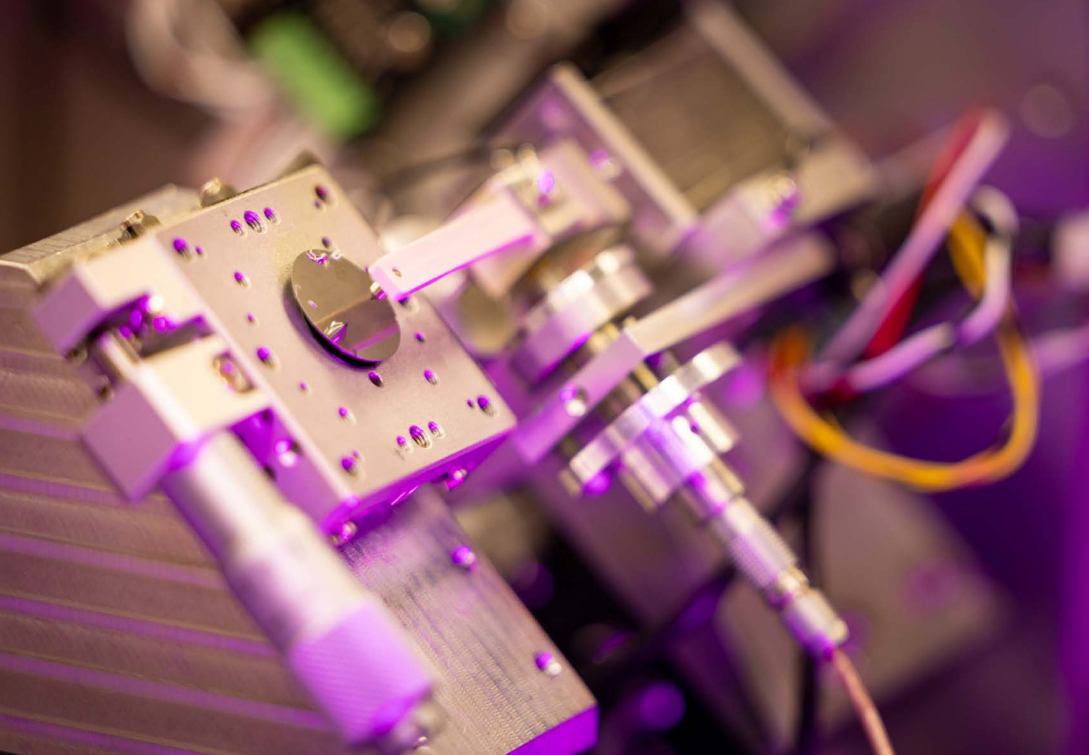
The NPL scratch tester is used to determine the resilience of engineered surfaces including coatings and surface treatments to scratching. Unidirectional scratches are made using diamond indenters. Indenter depth, friction force and acoustic emission are measured and recorded during each scratch and correlated with the applied load and sliding distance. The in situ wear and friction measurements are normally complemented by post-test 3D optical imaging.

Macro-scale scratch test

Simulates scratch damage to coatings and surfaces using an indenter with a ramping load of 2-200 N. Tests adhesion of coatings and resistance of surfaces. The friction force and acoustic emission generated can also be recorded to determine the critical load of failure.



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



Microtribology: NPL's micro tribometer capable of scratch tests inside an SEM enables friction measurements to be correlated with microstructural features.

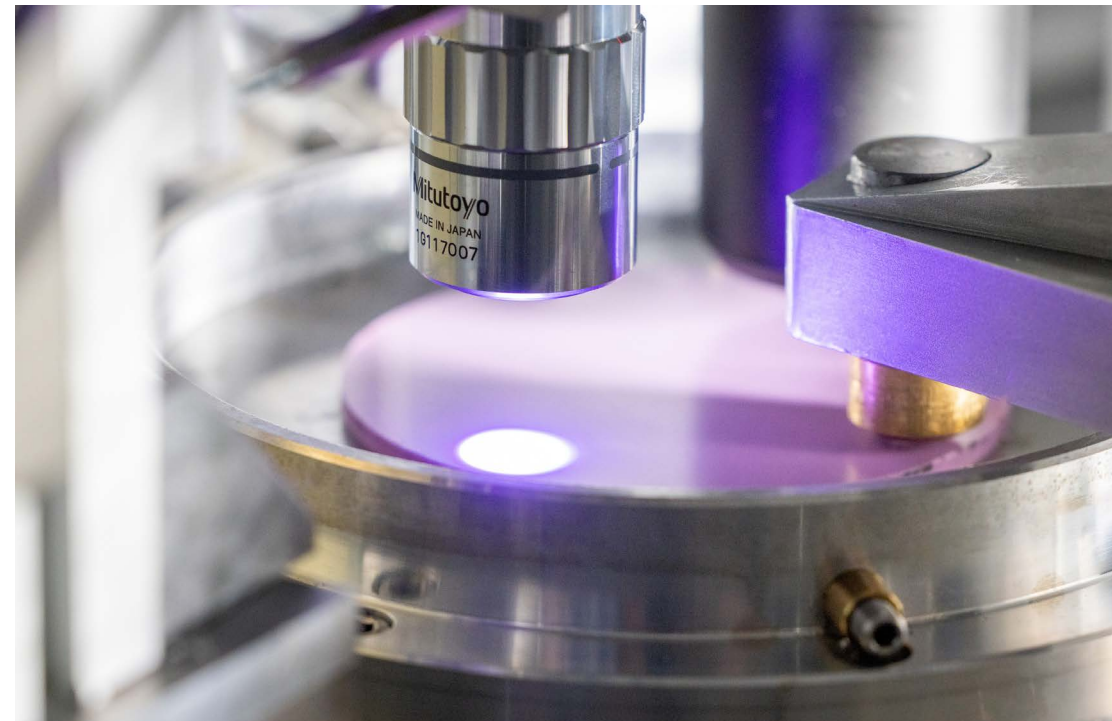
Microtribology

Simulates scratch damage and single abrasion events to coatings and surfaces using an indenter with a ramping load of <250 mN. Examines and models the response of a material's microstructure to abrasion by particles and asperity size contacts. Experiments can be observed using an optical microscope or in a SEM in situ to correlate friction with microstructural features.

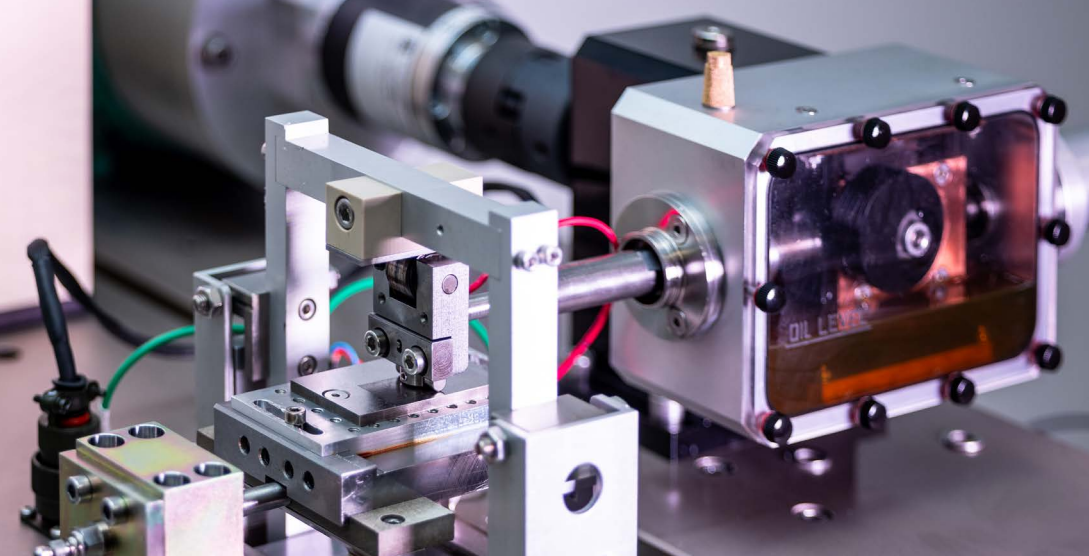
Sliding wear

Pin-on-disc (ASTM G99)

In pin-on-disc testing, a pin or ball is pressed against a rotating disc, and friction and wear displacement – the total movement of the pin towards the disc – are both measured continuously in situ with a unidirectional sliding tribometer (UST) and several sensors. Real-time measurements are taken using a line scan camera, a non-contact optical chromatic aberration probe and a self-zeroing friction measurement system. NPL offers this type of analysis for loads of up to 250 N and speeds of up to 2 m/s.



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.



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

Plint TE77 reciprocating testing (ASTM G133)

The Plint TE77 reciprocating tribometer simulates wear by pressing a pin or ball against a flat plate moving back and forth under controlled conditions. Wear is measured in situ by measuring the change in height of the roller head assembly using a probe. NPL's test system measures friction and wear displacement for dry or wet surfaces with loads up to 1 kN, at frequencies of up to 50 Hz, stroke lengths of 25 mm and temperatures of up to 600 °C. A small electric potential can be applied across the interface of the stationary sample and the reciprocating surface to indicate coating performance. Wear scars are analysed using profilometry, optical and scanning electron microscopy to assess material performance in different environments.

NPL also carries out complementary testing using real-time data acquisition, optical and electron microscopy, profilometry, nanoindentation and other advanced techniques to provide a more comprehensive, tailored view of a material.

[Visit our website to discover our full portfolio of tribology capabilities.](#)

Case study: Reducing erosion on wind turbine blades

The Energy Technology Centre Ltd (ETC) collaborated with NPL to enhance water droplet erosion testing for wind turbine blades. Erosion from water droplets can diminish turbine performance, leading to 3-5% power losses, with repairs being particularly costly in offshore environments. Traditionally, assessing material erosion involved halting tests for visual inspections and measuring mass loss, which was a labour-intensive and disruptive process. To improve this, NPL adapted an optical measurement technique – originally developed for high temperature particle erosion monitoring in power stations – for use in wind turbine blade testing. This method, combined with a high speed camera and specialised software, enabled real-time detection of micrometre-level changes in blades moving at speeds of up to 150 m/s. The feasibility study demonstrated the system's capability to accurately measure known defects, paving the way for further development. ETC is now seeking partners and funding to advance this technology, aiming to gain deeper insights into erosion mechanisms. Such advances could lead to better design, material selection and coatings for wind turbine blades, potentially increasing their lifespan and efficiency.

[Read the full case study](#)

Tribology research at NPL

Our industry- and academia-driven research is closely aligned with national interests, focusing on how tribology measurement methods can be used to understand material degradation under various conditions. We actively engage with stakeholders at conferences and in advisory groups, and are constantly working at the cutting edge of science, discovering ways that microstructural characterisation techniques – including optical and SEM microscopy, and FIB (focused ion beam) topography – can improve the integration and precision of testing methods.

For sliding wear testing, our focus is on developing methods that capture damage mechanisms as they occur, including systems for visualising wear accumulation using optical line scan cameras or in situ SEM imaging. We are advancing real-time wear depth measurement techniques using both contact and non-contact optical probes, and addressing the challenges of accurately measuring the low friction properties of modern carbon coatings. We are also exploring the measurement of small wear volumes through relocation profilometry.

Another line of research is looking at the continuous development of measurement methods for demanding environments for abrasion and erosion testing. For example, the NPL water droplet erosion test system is being optimised to enhance control over experiment variables, reducing variability and refining our understanding of the erosion process. Similarly, a high temperature solid particulate erosion test system is under evaluation, incorporating laser triangulation and in situ mass loss measurement for greater efficiency and accuracy.



Water droplet erosion: Designed and built by NPL the water droplet erosion facility is capable of accelerated testing at speeds exceeding 300 m/s.

New methods for characterising the mechanical properties of engineered surfaces at the right scale are being developed and validated, including high temperature nanoindentation. Micro-pillars and cantilevers, created via focused ion beam milling, are being tested under electron microscope observation. Additionally, micro-scratch tests using an NPL-designed apparatus within an electron microscope are providing detailed insights into coating durability and failure mechanisms. Other techniques supporting our work include laser surface acoustic wave measurements, micromechanical measurements of adhesion and fracture toughness for coatings.



Your trusted partner for bespoke surface analysis

NPL is the UK's National Metrology Institute, providing reassurance of our independence and the impartiality of our findings. Our globally recognised expertise and diverse skill set across complementary disciplines, coupled with our broad range of in-house technologies, enable us to provide tailored consultancy and testing solutions for every application. We pride ourselves on clarifying requirements, interpreting results and solving problems for our customers using our technology-agnostic approach and tried-and-tested methodology.

Get in touch with us to discuss how we can support your specific surface testing project.

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