Reciprocating nano-wear with the NanoTriboTest

Introduction

The NanoTriboTest module enables rapid high-cycle linear reciprocating nano-scale wear tests to be performed with track lengths up to 40 mm. Reciprocating contacts occur in a wide variety of practical wear situations such as (i) comb drives in MEMS (ii) hip joints and (iii) electrical contacts. In optimising materials for improved durability in these contacts it is important that the contact conditions (e.g. sliding speed) can be reproduced.

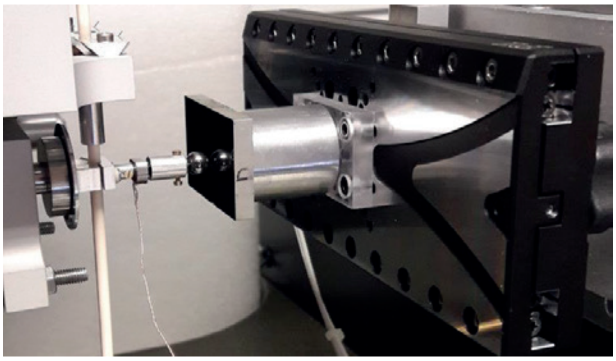

Figure 1 NanoTriboTest

The NanoTriboTest extends the range of nano-tribological tests possible with the NanoTest Vantage. Obtainable parameters including friction loops, energy dissipation per cycle (sliding distance *x* friction) and cumulative energy dissipation are automatically calculated in the NanoTest software.

The design of the loading head on the NanoTest Vantage provides a high level of lateral rigidity giving the stability to run wear tests for extended duration. By being able to combine data from different test techniques it is possible to obtain more detailed information about the failure mechanisms.

The NanoTriboTest module can be used in conjunction with the Electrical Contact Resistance (ECR) module.

Case Studies

1. Reciprocating wear of metallic materials

Nano-scale studies of the wear resistance of metallic materials under reciprocating sliding conditions are important to improve our understanding of their performance in mechanically loaded sliding contact, for biomedical applications. 500 cycle tests with the NanoTriboTest module were performed on highly polished medical grade Ti6Al4V and 316LVM stainless steel sliding over a 1 mm track at 0.5 mm/s. The normal load varied in the range 10-500 mN and the test probe was a spheroconical diamond of 25 μm end radius.

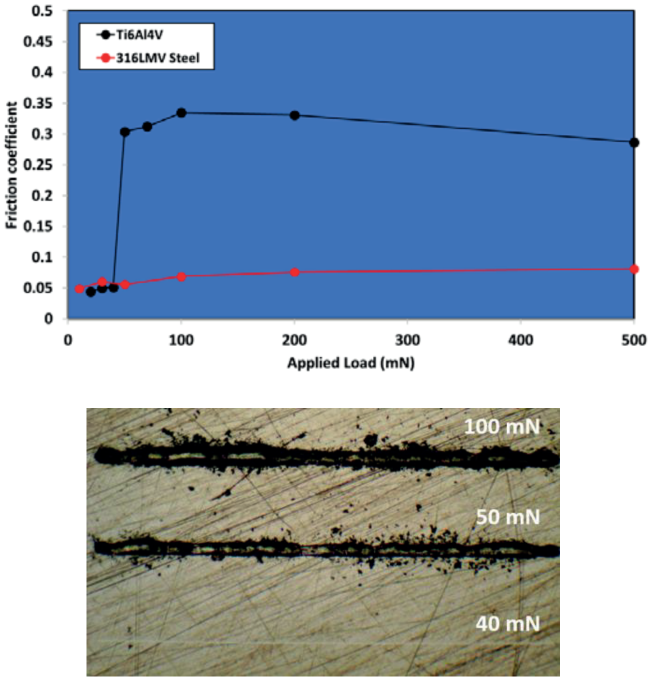

Figure 2 (a) Friction coefficient vs. load for Ti6Al4V and 316LVM steel. (b) tests at 40, 50 and 100 mN on the Ti alloy

Stainless steel showed ductile response throughout the load range but the Ti alloy was more brittle at higher load resulting in a transition to higher friction and wear during the test.

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2. Wear resistance of DLC films

(i) 180 nm soft sputtered amorphous carbon film on glass

1500 cycle tests at 100 mN with a steel test probe of 1 mm radius were performed over 2.5-10 mm track length at 2-5 mm/s. Illustrative friction vs. sliding distance data during a test with velocity = 2 mm/s and track length = 10 mm (total sliding distance = 30000 mm) are shown below. Friction loops are determined from this data and the energy dissipation calculated. The soft film failed by a gradual wearing through of the film followed by fatigue failure at the edge of the wear track resulting in an increase in the dissipated energy and its variation with each wear cycle.

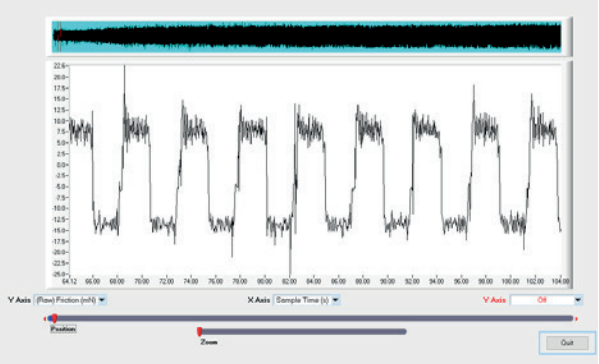
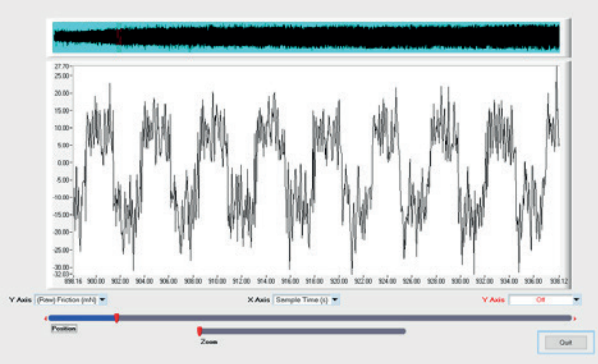


Figure 3 Friction measurements (a) before and (b) after film failure.



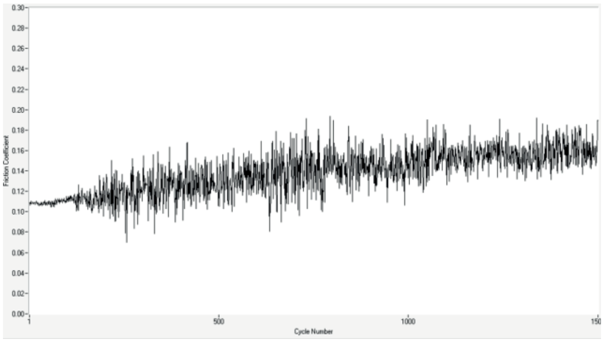


Figure 3 (c) The transition between the two regimes is clearly seen in the onset of more variation in the friction and dissipated energy per cycle from ~120 wear cycles.

(ii) Multilayer hard DLC on steel

500 cycle tests at 2-100 mN with a diamond indenter with 25 µm end radius were performed over 1 mm track length at 0.5 mm/s. Under these conditions the multilayer DLC was resistant to wear at 2-50 mN but failed during the test at 100 mN.

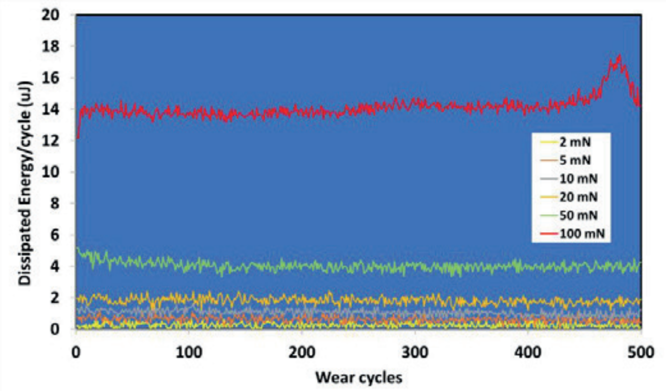


Figure 4 (a) Energy dissipation vs. wear cycle

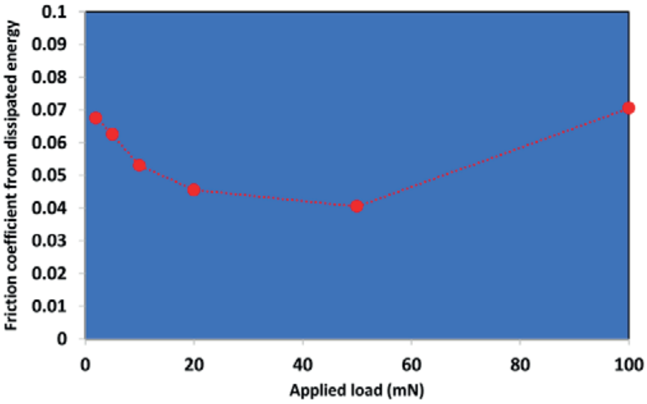


Figure 4 (b) Load dependence of friction determined from dissipated energy

At low load the high surface roughness increases the friction. At higher load the asperities are more effectively ploughed out and the friction decreases. Total failure occurred during the test at 100 mN, resulting in film delamination outside of the scratch track.

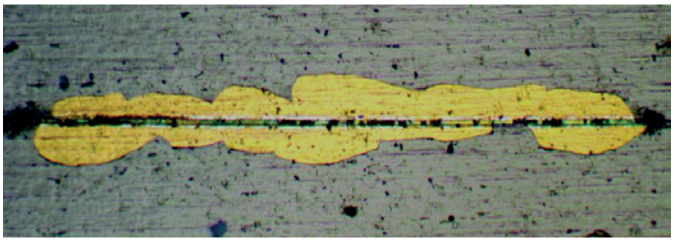


Figure 4(c) Film failure at 100 mN

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3. Electrical Contact Resistance Measurement

Electrical contacts need to display low and stable resistance. Even single spikes in contact resistance can result in data loss that can be particularly important in safety-critical applications. Damage can occur with tribo-oxide formation and, to mitigate this, noble metals such as gold or silver and their alloys are commonly used to extend the endurance of the sliding electrical contact. The durability of electrical contacts can be studied by fretting, or more conveniently under the full sliding conditions in the NanoTriboTest which can result in accelerated wear, e.g. to due to the break-up of protective oxides. In the following examples the endurance of different electrodeposited alloys has been evaluated using the NanoTriboTest in conjunction with the ECR module.

(i) Gold vs. steel

An electroplated gold alloy disk was worn at 10 mN by a 1 mm radius steel ball at a sliding velocity = 2 mm/s and track length = 5 mm. Tests were feedback controlled with a fixed current of 0.5 A. Under these conditions the gold alloy disk showed low endurance typically failing after ~60 cycles. In these tests the electrical and tribological behaviour was intimately connected. Changes in contact resistance and dissipated energy as the test progressed were strongly correlated and enable the wear mechanism to be investigated. Wearing through of the top layer resulted in electrical failure and higher dissipated energy. Typical examples are shown in the figure below.

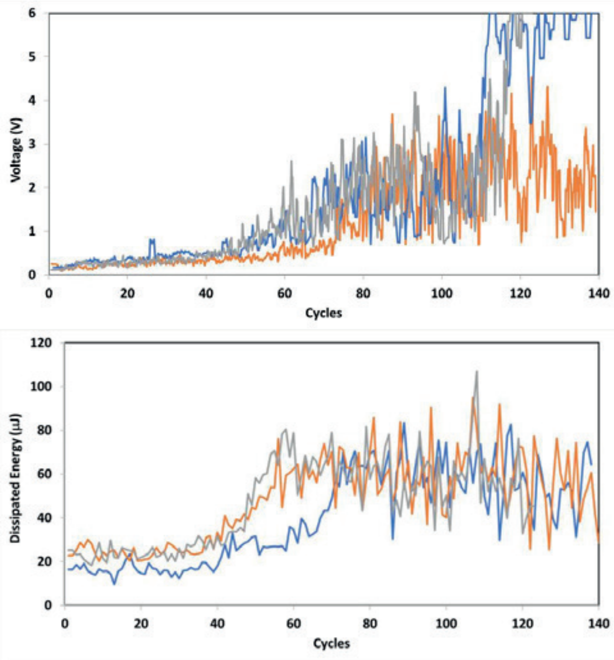

Figure 5. Three illustrative repeat tests on Au alloy disk vs. steel. (a) Voltage (b) corresponding dissipated energy. For clarity the voltage is shown as a 3-point moving average.

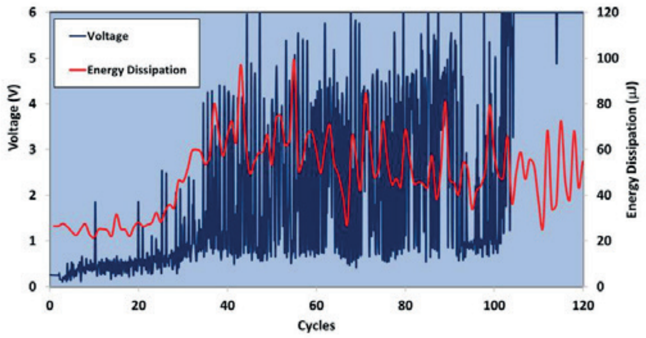

Figure 6. Energy dissipation and Voltage (raw signal) evolution during sliding between gold and steel.

It is clear that the energy dissipation increases markedly at the point at which the baseline electrical voltage starts to increase (~25 cycles) resulting in rapid total failure after ~35 cycles.

(ii) Noble metal-noble metal sliding

Noble metal-noble metal contacts displayed much longer endurance than gold vs. steel. An example of gold disk sliding against a gold alloy connector at 20 mN and sliding against 1 mm radius steel ball at 10 mN is shown in figure 7.

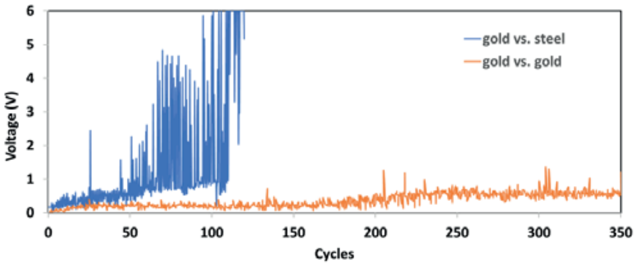

Figure 7 Comparison of Au-Au and Au-steel contacts.

Silver alloys similarly show excellent durability in sliding vs. noble metal connectors. Sliding tests were performed on Ag alloy electrical connectors with different alloy composition and geometry against Ag alloy disks at 50-200 mN, with the set point current being 0.1-0.5 A. Under these conditions they displayed high endurance with some isolated failures in a 35000 cycle test taking 46 hrs.

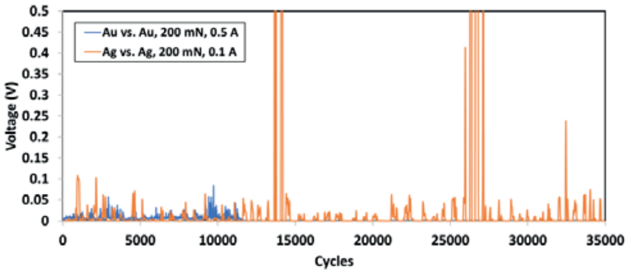

Figure 8 Extended testing of Au-Au and Ag-Ag.

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NanoTest nano/micro-tribology specifications

Reciprocating wear tests are also possible with the nano-scratch, nano-fretting modules but there are key differences between them. A comparison of typical experimental conditions in the different tests is shown in the Table below.

	Nano-scratch	Nano-fretting	NanoTriboTest
Probe radii (µm)	**5-25**	**10-200**	**25-5000**
Applied load (mN)	**0-500**	**0-500**	**0-500**
Sliding speed (mm/s)	**0.001-0.1**	**0.01**	**1-10**
Scan distance per cycle (mm)	**0.01-1**	**0.02**	**1-10**
Number of cycles	**1-20**	**1000-200000**	**100-30000**
Total sliding distance (m)	**0.00001-0.01**	**0.01-0.1**	**1-300**
Wear depth measurement	**Y**	**Y**	**Y**
Friction measurement	**Y**	**Y**	**Y**
ECR compatibility	**Y**	**Y**	**Y**

Typical sliding conditions in nano-scratch, nano-fretting and reciprocating wear tests

In the nano-scratch test the contact pressure is typically high (>> 1 GPa) and the test can be dimensioned so that the peak stresses are placed in the vicinity of the interface.

In the nano-fretting test the stresses are typically lower but the small track length means that total sliding distance is relatively low, and the transition from fretting/partial slip to gross slip can be studied.

In the NanoTriboTest the sliding speeds are much greater allowing much larger sliding distances. Maximum track length = 40 mm.

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Conclusions

1. The NanoTriboTest module delivers the same very high level of measurement stability as other experimental techniques in the NanoTest range.

2. This excellent durability provides the opportunity to perform very high cycle and long sliding distance nano-tribological tests. Automatic calculation of energy dissipation per wear cycle and the friction coefficient determined from this provides a powerful in-situ tool for examining the wear process.

3. By being able to combine data from different test techniques it is possible to obtain more detailed information about the failure mechanisms. The NanoTriboTest module can be used in conjunction with the Electrical Contact Resistance (ECR) module.

4. The combination of ECR and dissipated energy measurements enables the onset of electrical failure to be studied in detail.

NanoTriboTest Benefits

- Stability for long-duration testing
- Accurate recording of cycles to failure
- Dissipated energy, friction coefficient, wear depth recorded throughout the test
- Combination with Electrical Contact Resistance
- Detailed information on wear mechanisms
- Combine with other NanoTest techniques (e.g. nanoindentation, nano-scratch) to build up a more complete picture of mechanical properties and tribological behaviour