Describing atom by atom wear mechanisms

The apprehension of friction and wear mechanisms at the nanometer scale, known as nanotribology, is of huge interest for both scientific and technologic fields. On the fundamental side, friction and wear is a universal phenomenon that is manifested in many natural behaviors such as earthquakes, landslide and granular physics. On the technological side, the emergence of miniaturized mechanical systems and nanotechnologies requires reducing friction and wear in order to improve the system autonomy, durability, and to minimize their economical and environmental costs. However, phenomena involved in friction and wear mechanisms are far from being well understood. The development of Atomic Force Microscopy (AFM) offers new opportunities for a better understanding of the elementary mechanisms of friction and wear at the nanometer scale as it offers the possibility to generate a mono-asperity contact between the AFM tip and the sample. The principle of an AFM is to scan the sample surface with a very sharp tip, with a back and forth displacement, while measuring the normal and friction force between the tip and the sample.

Recently, we have developed at the Laboratoire Roberval (Université de Technologie de Compiègne) within a collaboration with the Institute of Molecules and Materials of le Mans (Université du Maine), a new AFM mode called the circular mode (Fig. 1). The principle of this mode is to generate circular displacement at high frequency. This mode exhibits many advantages for friction and wear measurement compared to commercial AFM modes. The first one is to perform very fast and accurate measurement of the friction force as a function of the load [1-2]. The second one is to perform well define wear tracks (Fig. 2) that could enhance atom by atom wear process. This latter phenomenon that is only slightly described in the literature.

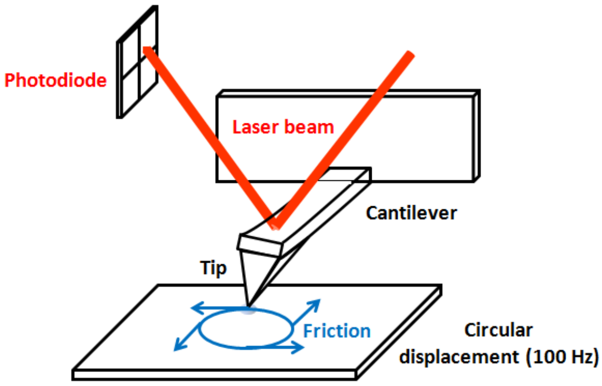

Fig. 1: Principle of the AFM circular mode. The tip, attached to a cantilever is in contact with the sample and animated by a circular displacement. Normal and friction forces generate flexion and torsion of the cantilever that are detected by the deviation of the laser beam

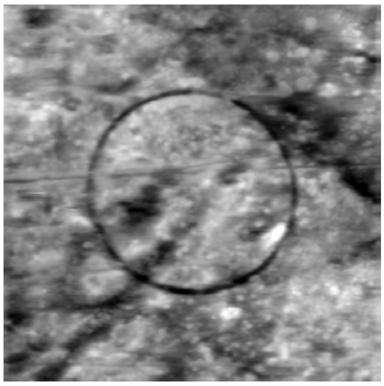

Fig. 2: Topographic image (x-y scale 5µm, z scale 38nm) of a wear track generated by the AFM in circular mode. The wear track is well defined and the wear volume could be easily computed

The objective of this PhD is thus:

- To develop the capability of this new AFM mode in order to describe accurately the atom by atom wear process.
- To describe the wear law as a function of the experimental parameters (load, friction force, sliding velocity, energy dissipated, etc…) for different model samples
- To compare experimental laws with theoretical models

[1] Nasrallah, H., Mazeran, P.-E., Noël, O., Circular mode: A new AFM mode for investigating surface properties, Review Scientific Instruments, 82 (2011) 113703

[2] Noel, O., Mazeran, P.-E., Nasrallah, H., Sliding velocity dependence of adhesion in a nanometer sized-contact, Physical Review Letters, 108 (2012) 015503

Goals of the research

The main goal of this project if to develop and illustrate the ability of a new Atomic Force Microscopy (AFM) mode to characterize wear at the nanoscale. Preliminary works realized with this new patented called circular mode (US Patent 8997261 B2 (Mar. 31. 2015)) has shown a very good ability to measure atom by atom wear. The knowledge of atom by atom wear mechanisms and laws is needed to predict and improve the durability of mechanical devices.

The development of micro and nanotechnologies has increase the number of micro and mechanical system manufactured by the silicon technology. This technology use materials (silicon based materials, thin films…) that are generally not used in classical mechanics and the ability of this material to resist to wear is far to be known.

There is a high number of materials and surface treatments that change the mechanical properties in the very close surface. Resistance to wear could be measured by classical macroscopic wear tests but are generally measured for plastic contact on rough surfaces. This wear laws are not useful when the wear mechanisms generate very low wear as for example in electrical switches or more generally in elastic contacts. The interest of our method is to break free of the roughness of the sample by generating a local wear (a few nanometers depth) that take into conditions the local variation of properties as for example crystallographic direction.

Last but to the least, data performed in this study could bring important information that could help to understand the elementary mechanisms of wear at the nanoscale that are far to be understood.

Experimental methods

The experimental methods are mainly based on the skills developed in the laboratory in particular AFM in circular mode. The principle of this mode is to generate circular displacements of the AFM tip at high frequency. It has been developed to measure adhesion, friction and wear at the nanoscale. The advantages of this mode is to perform very fast and accurate measurements of adhesion and friction laws at high, continuous and constant sliding velocity. It also allows to perform well defined wear tracks that could evidence atom by atom wear process. The aim of this project is to develop and illustrate the potential of the AFM circular mode for atom by atom wear using a model materials and an application materials (Copper alloys used in electrical switches).

Furthermore, some others experimental tools will be used:

1) Electron Microscopy and Atomic Force Microscopy in imaging modes for measuring wear tracks.
2) Polishing machines
3) Nanoindentation and scratch tests for measurement of the hardness

Time plan

<u>0-6 months : Research preparation</u> :

- Bibliography on wear at the nanoscale, especially by Atomic Force Microscopy.
- Acquisition of skills and autonomy in Atomic Force Microscopy, more particularly :

1) Calibration of lateral force
2) Calibration of tip radius
3) Practice of AFM circular mode and AFM imaging modes
4) Practice of Nanoindentation and characterization of Mechanical properties
5) Practice of Data and Image treatment

6-15 months : Experiments and data treatment

- Determination of the wear laws on a model material:

1) Selection of the model material (metal probably stainless steel, with the lowest roughness)
2) Preparation of the sample
3) Determination of the friction laws and the influencing parameters (velocity, load, tip radius…)
4) Control of the tip wear
5) Observation of the wear tracks and wear particles

15-21 months : Complementary experiments , results analysis and writing of the first publication

21-30 months : Experiments and data treatment

- Determination of the wear law on a composite materials (copper alloys with alumina particle)

1) Preparation of the sample
2) Determination of the friction laws and the influencing parameters (velocity, load, tip radius…)
3) Control of the tip wear
4) Observation of the wear tracks and wear particles

30-36 months : Complementary experiments, results analysis and writing of the second publication

36-42 months : Writing of the first phD manuscript and phD defense