Materials characterization and tribological parameters determination of its worn surfaces

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Materials characterization is important when we want to determine features of different surfaces that are used in many areas. Tribological parameters help to this type of characterization, mainly for worn surfaces. There are techniques with complex mechanisms that allow to obtain these parameters and to observe all the surface characteristics. We are using an atomic force microscope and a roughness tester in order to characterize femoral head surfaces and component parts made of steel, titanium alloys or CoCr alloys.

1. Introduction

Generally, a surface deteriorates due to the pressures produced by mechanical movements of the systems it is part of.

The deterioration process varies from one system to another, in some cases with a complex mechanism. An example is the hip prosthesis, which wear mechanism combines the abrasive wear, adhesive wear, wear with the third body and wear by fatigue [1] (Fig. 1). These wear mechanisms also occur for different mechanical and biomechanical systems.

Abrasive wear [2] represents the removal of material from one surface by the other. Local high points or "asperities" on the surface of the harder material will produce into the softer material wear particles.

Adhesive wear is produced where localized bonding of the two surfaces occurs, such that the attachment force is stronger than the yield strength of the material. A small piece of material is removed from one surface and is attached to the other.

In a physiological environment, metallic, ceramic or polymeric wear particles may be trapped between two moving surfaces, causing three-body wear [3].

Fatigue wear can lead to subsurface cracks propagating and flaking off of particles from the surface. High subsurface stresses can also be caused by third bodies between the two articulating surfaces leading to accelerated fatigue wear.

2. Techniques for characterization and determination of tribological parameters

Wear processes occurring inside different systems are an important source of wear particles, but these changes are often impossible to see with the naked eye. A methodology of ascending degrees of resolution was established using macroscopic (resolution millimeters), microscopic (resolution microns) and nanoscale (resolution nanometers) measurements.
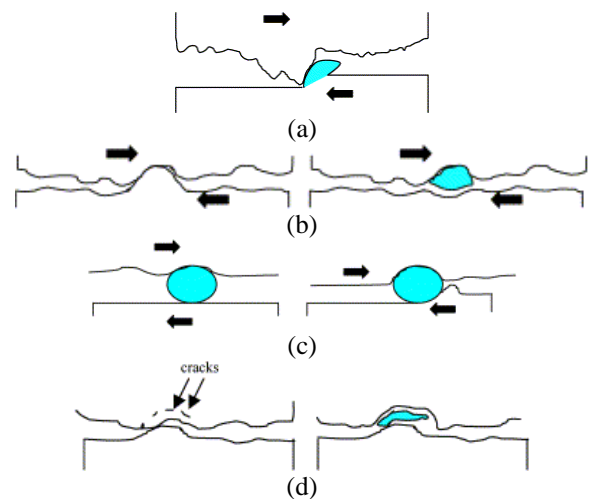

Fig. 1. Wear mechanisms [1] (a) Abrasive wear mechanism(b) Adhesive wear mechanism c) Third body wear mechanism(d) Fatigue wear mechanism.

In addition, characterization of worn surfaces and determination of its tribological parameters can be achieved by various experimental techniques. Some of these are non-contact surface measurements using atomic force microscope, confocal microscope, scanning interferometer or triangular laser.

3. Mechatronic systems used for characterization of materials surfaces

At INCDMTM, characterizations and determinations of tribological parameters for surfaces containing different materials are realized. For example, is determined surfaces roughness of some femoral heads from hip prostheses realized by steel, CoCr, steel coated with TiN; polycrystalline diamond compact surfaces COMPAX 1321; steel – component material of different mechanical parts.

For these measurements we are using an atomic force microscope (Microscop Probe NTEGRA - Fig 2) working

in the non-contact mode and a roughness tester Talysurf PGI.

Working principle of AFM is to measure the interaction force between tip and sample surface using special measuring heads, made of a cantilever with a pointed end. AFM images are processed using Nova SPM software. In this way is obtained the roughness of the studied surface and can be calculated other tribological parameters.
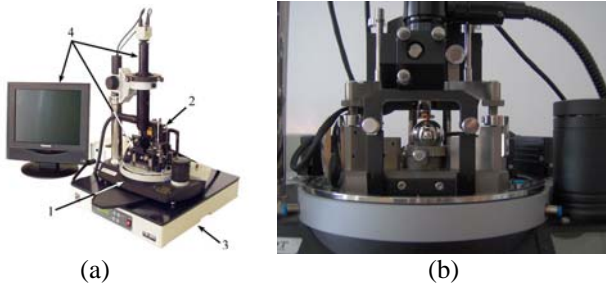

(a) (b)

Fig. 2. Atomic Force Microscope NTEGRA Probe NanoLaboratory: a) 1 – base unit; 2 – measuring head; 3 – vibration isolation system; 4 – optical viewing system;
b) detail of a hip prosthesis AFM measurement.

The samples are positioned on the base unit of AFM using a robotic nanomanipulator that has more degrees of freedom including rotation for control of orientation and thus, can be used to manipulate 0D objects (spherically symmetric) to 3D objects in space.

A Hexapod positioning system for Micro-Movement, F-206 (Fig. 3), is used in this experiment [4]. 6-axis positioning system F-206 consists of an attachment position system (Fig. 3a) and a control unit (Fig. 3b). A keyboard and a monitor for the control unit (either included or connected as a peripheral device) may be used to control F-206 system directly or, typically, the control unit can be controlled by a PC. System's mechanics uses a parallel - cinematic positioning system. The system provides 6 degrees of freedom and a minimal increase of movement of 0.1 μm. Workspace boundaries are not parallel to the axes, but it cannot overcome a rectangular solid which is given by the limits of movement X, Y and Z. The control unit is equipped with integrated software to define a pivot point anywhere inside or outside workspace of F-206 system. Rotation around this pivot point may be ordered for any combination of the 3 rotation axes. Digital command system processes complex positioning and elements of movement, including scanning procedures and alignments using optical or analogue response signals from more than 2 meters.

All orders for positioning "F-206 platform" are given in orthogonal coordinates and converted by command system in F-206 specific actuator positions and speeds before making the action.

The connection between NTEGRA Atomic Force Microscope and the Hexapod positioning system for Micro-Movement F-206 is done with a finger device (gripper) that allows nanopositioning of samples used. A scheme of the obtained complex system used to characterize and analyze the studied surfaces is presented in the Fig. 4.
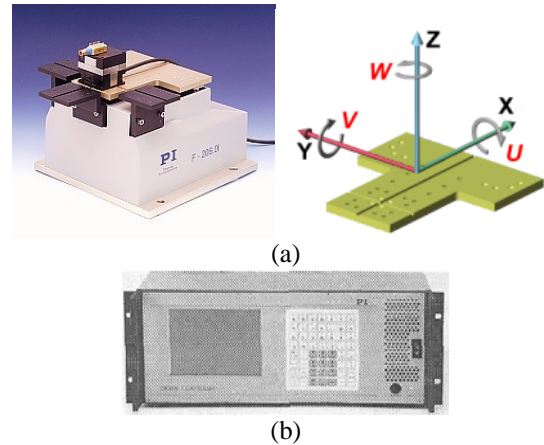

(a)

(b)

Fig. 3. F-206 alignment and positioning system with six axes: hexapod positioning system (a) and control unit (b) (a) Hexapod positioning system – all commands and operations are using (X, Y, Z and U, V, W) coordinates. Travel range: X = -8 to +5.7 mm, Y = ±5.7 mm, Z = ±6.7 mm, U = ±5.7°, V = ±6.6°, W = ±5.5°. (b) Control unit.
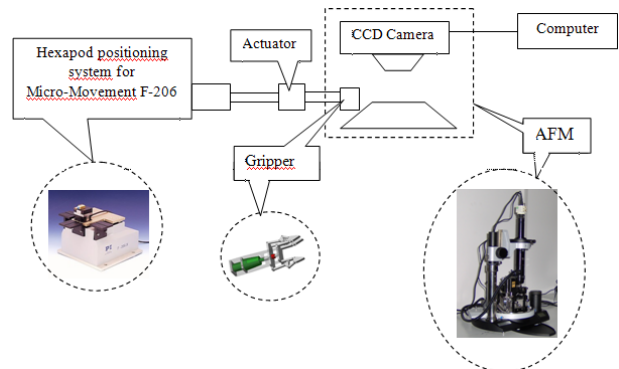

Fig. 4. Complex mechatronic system made up of NTEGRA Atomic Force Microscope and F-206 alignment and positioning system with six axes.

In our institute, to determine the tribological parameters, especially roughness, the Talysurf PGI Instrument roughness tester is also used (Fig. 5a). The main components of such a device are shown schematically in Fig. 5b. The stylus is moved on the surface and its transducer converts its vertical movements into an electrical signal which is amplified and used to operate a recorder. From this filtered signal was derived R_a value that is presented on an indicator.

4. Laboratory results concerning the tribological characterization and determination of surfaces

Using AFM measurements can be determined exactly the surface roughness and can be seen all surface projections. In our institute were carried out characterizations and determinations of tribological parameters of different surfaces: CoCrMo (Fig. 6), TiN (Fig. 7), Ti6Al4V (Fig. 8), (area of the femoral heads of hip prostheses) and polycrystalline compact diamond COMPAX 1321 (material that can be used as an active part of a lathe tool for processing metallic/non-metallic materials).
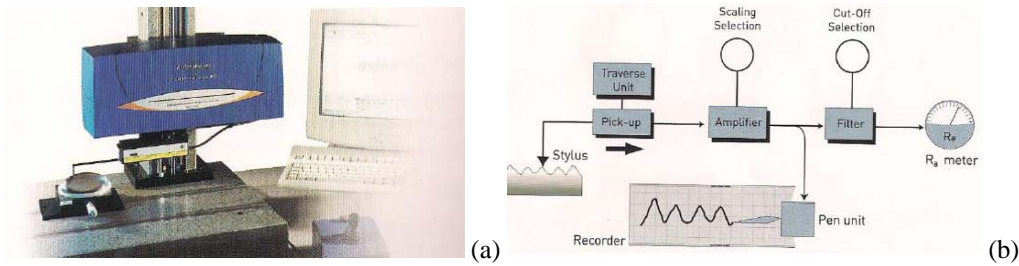
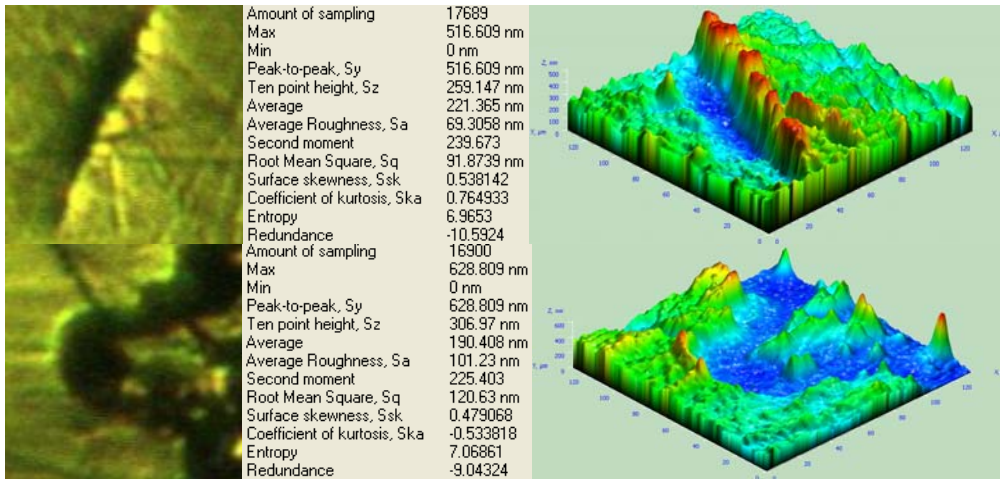Fig. 5. Talysurf PGI (a) and components diagram of a measuring system of a surface texture (b)

Fig. 6. Characterizations and tribological determinations of CoCrMo surfaces using NTEGRA atomic force microscope As it is shown in the examples presented, roughness has different values (in different parts of the same femoral head) depending on the movements of the body that uses the prostheses.
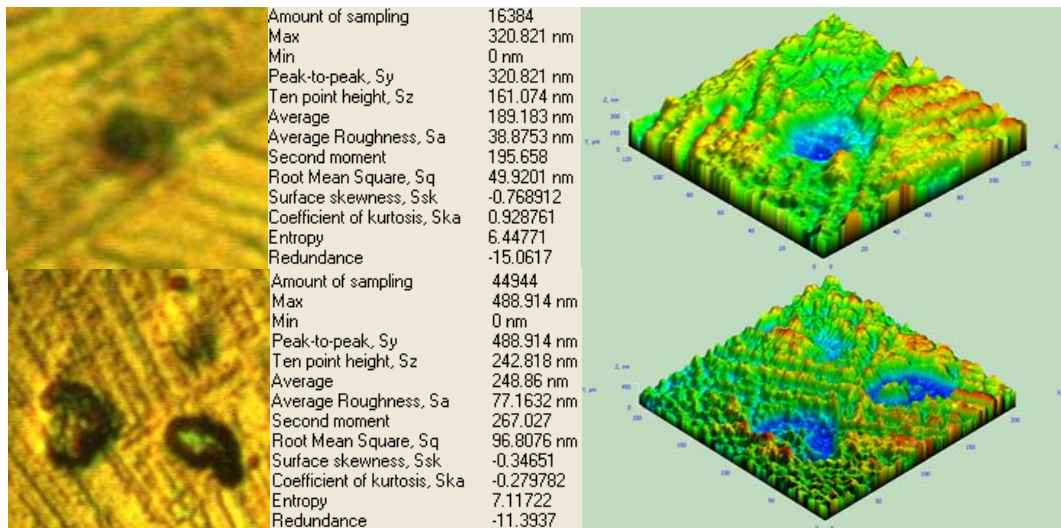

Fig. 7. Characterizations and tribological determinations of TiN surfaces using NTEGRA atomic force microscope.

After a few experimental results it was observed that friction is lower for TiN. From the tribological point of view, a favorable coating material must have an elastic modulus, which is similar to the substrate material and has good adhesion to the substrate. In addition, it was observed that low-friction materials are the best to reduce the effect of temperature risks.
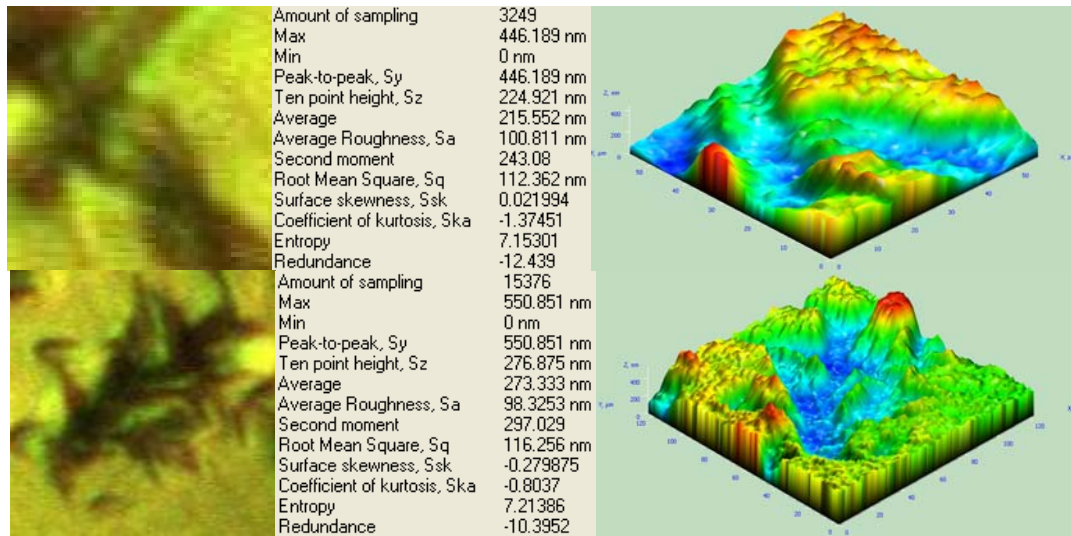
Fig. 8. Characterizations and tribological determinations of Ti6Al4V surfaces using NTEGRA atomic force microscope.

Besides the hip prostheses surfaces characterization, were also characterized several polycrystalline compact diamond COMPAX 1321 surfaces. Tribological parameters obtained can be seen in Fig. 9, together with the 3D image of the worn surface.

Some results of roughness measurements of steel parts made with the Talysurf PGI roughness tester are shown in Fig. 10.

Fig. 10. Surfaces roughness measured by Talysurf PGI roughness tester.
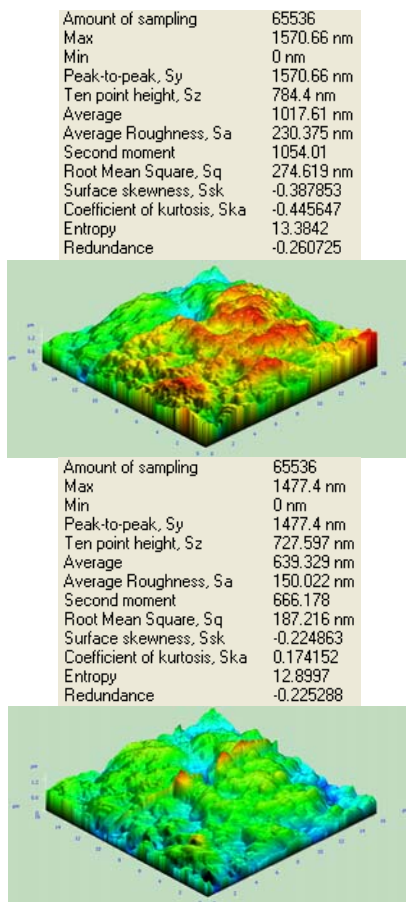
Fig. 9. Characterizations and tribological determinations of polycrystalline compact diamond COMPAX 1321 surfaces using NTEGRA atomic force microscope
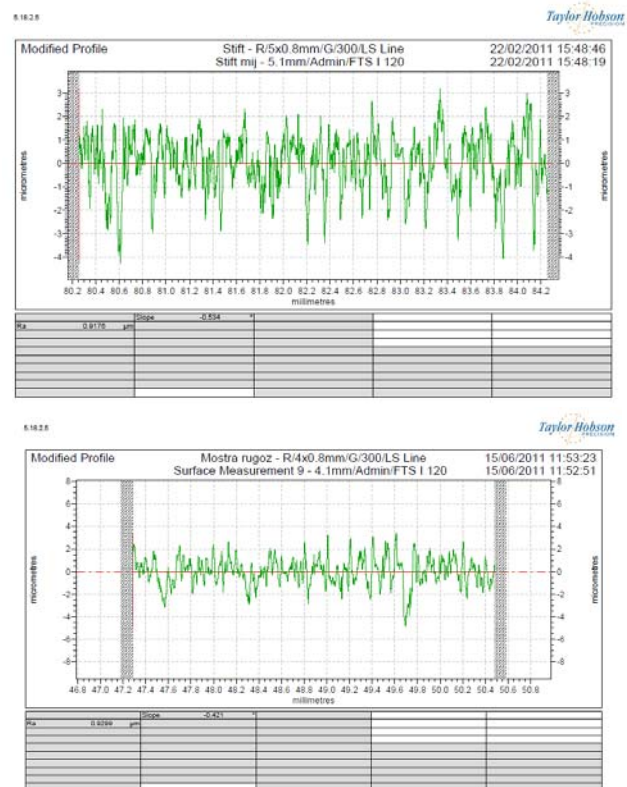
5. Conclusions

In order to obtain a clear characterization of realized parts surfaces or the coatings from the femoral head of a

hip prostheses the study of its topography and roughness determination are useful. Such a study can be made by different techniques and different systems. AFM was used because its images display high quality and dense nanocrystalline structure of prepared thin films. NTEGRA Probe Microscope has been connected with a Hexapod positioning system for Micro-Movement F-206 in order to obtain a complex positioning of the sample, followed by surface characterization and determination of few tribological parameters. Taylor PGI roughness tester is also a system that can determine the exact roughness values of different parts (in this case, steel).

Taking into account all these studies we shall continue the research using these systems, which can improve the surfaces topography characterization.

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