NANOTRIBOMETER INSTRUMENT AS A TOOL FOR INVESTIGATIONS IN NANOTRIBOLOGY

Fatima Živić [1], Miroslav Babić[1], Slobodan Mitrović [1]

Keywords: Nanotribometer, friction coefficient, nanotribology

ABSTRACT

New, high tech industries and knowledge-based traditional industries, with application of research results from laboratory investigations at nano- and micro-scale shape the future development trends of industry in general. Integration of technologies for industrial applications with focusing on new technologies, materials and applications to address the identified needs by the different areas of human life has become a priority for researchers, among which, nanosciences have a distinguished role. Nanotribometry has become a powerful tool for helping resolving diverse issues in multidisciplinary approach.

1. INTRODUCTION

Considering the fact that nanotechnology deals with material at nano level, devices that can assist at monitoring and measuring appropriate features of such a system are of great importance. This paper deals with important characteristics of nanotribometer, which as an instrument that enables researches to quantify tribological properties of observed material at the nano level, represents valuable specialized laboratory equipment for investigations in this area.

The measurement of friction force and the calculation of the coefficient of friction are of great importance for many tribosystems and for some it is even especially critical, like for brakes, clutches or similar control system, where the friction force determines the system behavior. Another major challenge is to anticipate the type of wear to which a components will be subjected and accordingly applying a specific model of testing. Surface modeling, from various aspects like contact type, temperature, lubricating modes and other case based important features, are also crucial for other types of testing.

Conducted experiments that have been realized throughout the tribology laboratories showed that tribological performance is determined by material properties of the first one hundred nanometers [1]. Nano-instruments can provide good tool to study tribological behaviour of materials at nano-level. It is stated that era of nanotechnology started with the discovery of scanning tunneling microscope (STM) device, in 1981., for which, the Nobel Prize in Physics has been awarded to Heinrich Rohrer and Gerd K. Binning, who invented it, in 1986 [2]. Discovery of STM lead to development of different types of scanning devices, including atomic force microscope (AFM).

2. NANOTRIBOMETRY

Tribometry, in general, represents an area of tribology that comprises means and methods of measuring: friction forces in contact zones; wear of tribosystem elements; temperature; surface roughness; contact surfaces sizes; contact strain etc. Ѱβ The measurement of friction force and the calculation of the coefficient of friction are of great importance for many tribosystems and for some it is even especially critical, like for brakes, clutches or similar control system, where the friction force determines the system behavior. Another major challenge is to anticipate the type of wear to which a components will be subjected and accordingly applying a specific model of testing. Surface modeling, from various aspects like contact type, temperature, lubricating modes and other case based important features, are also crucial for other types of testing.

Each tribosystem has its own set of dominant characteristics and way of working. It is impossible to select one method test that suits the needs of every possible case where tribological testing is needed. The selection of appropriate test methods to meet engineering requirements is rather complicated. Depending on the observed case, functional requirements are analyzed and after them a suitable testing procedure is adopted.

Tribological behavior of a material at nanoscale has to be studied with rather different set of observed characteristics compared to the previous traditional approach (Figure 1.). As such, it is of a great importance to investigate phenomena and manipulation of matter at the nanoscale. Application of such a knowledge can and will lead to introduction of new forms of manufacturing, new products and services. Also, there are number of

[1] Faculty of Mechanical Engineering, Tribology Center, S. Janjic 6, 34 000 Kragujevac, SERBIA

possible environment related issues that nanosciences promise to resolve in close future.

Universal friction laws can be studied at different scales (nm, σm, cm), therefore explaining various issues between macro- and nano- tribology. Friction issues at tribosystems, from aspect of energy dissipation at contact interface have been investigated by means of nanotribometry.

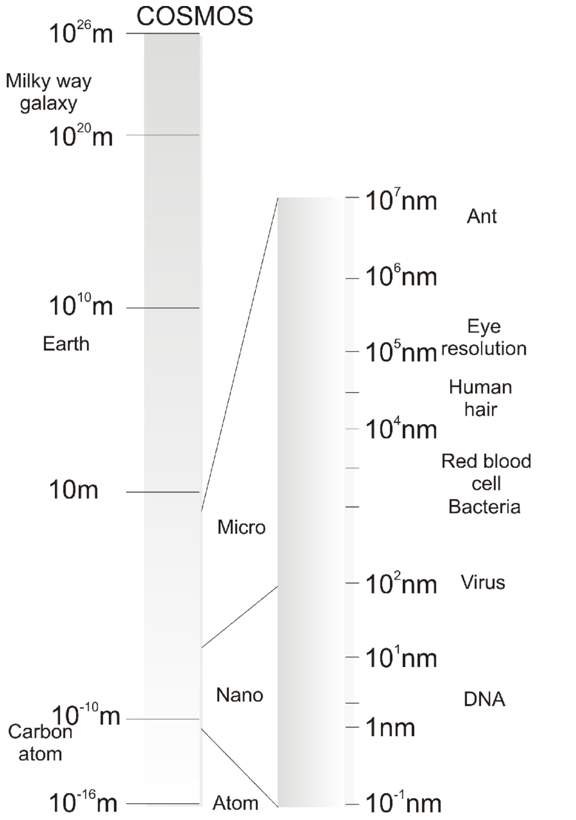

Figure 1. Material at nanoscale

Conducted experiments that have been realized throughout the tribological laboratories showed that tribological performance is determined by material properties of the first one hundred nanometers [2]. Nano-instruments (Figure 2.) can provide good tool to study atomic mechanisms of various lubricating characteristics, like lubricant spreading, lubricant behavior during contact etc.

Figure 2. Nanotribometer instrument

Theoretical studies on atomic scale friction still need to be acknowledged from practical aspects. Nanostructures created between the surfaces in relative motion are crucial for energy dissipation mechanisms. The future trends of research in this area anticipate possibilities of engineering frictional surfaces in such a manner that they would satisfy predefined conditions regarding friction coefficients. Molecular dynamics and statistical simulations offer powerful tool for such investigations together with development of modern laboratory tribometry devices, such as nanotribometer.

There are many areas of interest to study from aspect of nanotribometry and many broadly different ranges of applications where researchers have been doing investigations through various means of testing at nanoscale. Very important part of nanosciences, in general, is research work in area of new materials and new production technologies development. There are number of already implemented new materials which greatly improve specific systems under study.

A significant increase is expected in the near future in application of, for instance, aluminium and its alloys, especially the recycled material, in the construction and automotive industries, due to existing possibilities for surface treatment and tailoring of the surface properties according to requirement, in addition to the favourable strength/weight ratio of the material. There is, therefore, a need to develop a fundamental understanding of the surface properties of aluminium-based materials and products.

It is very important to connect, in more extent, existing theoretical findings with practical data obtained from some tribometry device. Information on, for instance, modelling the probing tip for realized frictional experiments is of significant importance for further advancements in understanding mechanisms of nanoscale friction.

3. NANOTRIBOMETER INSTRUMENT

There are many well established techniques for the measurement and characterization of bulk materials and their surfaces that are successfully applied in tribological investigations. A number of specialized techniques according to specific problems have also been established and applied across tribo-laboratories.

Widely applied device for performing measurements in tribology is tribometer device. Tribometer is defined as following: 1) An instrument or testing rig to measure normal and frictional forces of relatively moving surfaces; 2) Any device constructed for or capable of measuring the friction, lubrication, and wear behaviour of materials or components Ψβ

For nano-scale testing of friction and wear, nanotribometer is applied. The nanotribometer is based on a scanning force microscope design. The cantilever is associated with two optical sensors for measurements of its normal and lateral deflection during sliding against selected specimen, according to which the friction coefficient is determined.

It was designed to overcome the gap in ranges of testing between scanning force microscopy and standard wear test devices. Range of operation for which nanotribometer is used compared to scanning force microscopes and standard pin-on-disk tribometer is shown in Figure 3. The nanotribometer allows a much greater variation in contact conditions, and is therefore very well suited for tribological study of materials at very low loads. It is designed to operate at contact dimensions spanning from less than 1 nm to approximately 10 μm while applying the load in the nN to mN range Ψ4β

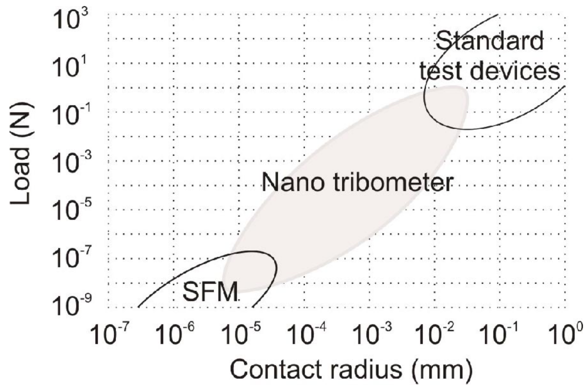

Figure 3. Nanotribometer range of operation

CSM Nanotribometer is an instrument that enables low load range down to 50 μN Ψ4β It is equipped with a depth measuring sensor which is important in studying the time dependent wear properties (depth range 20nm-100μm; depth resolution 20nm). Furthermore, it can have various options regarding the control of environmental characteristics (high/low temperature, humidity or lubricating mode), contact pressure, speed, frequency or time. This way, real life conditions can be reproduced through laboratory simulation by this instrument.

Linear reciprocating module of nanotribometer is used for simulation of many real life cases, where typical reciprocating motion is present. Most contact geometries can be reproduced including Pin-on-Plate, Ball-on-Plate and Flat-on-Plate. It is equipped with appropriate software that can generate wear rates or do calculation of the Hertzian stress.

Linear reciprocating module of nanotribometer setup is shown in Figure 4. This nanotribometer module reproduces the reciprocating motion typical of many real world mechanisms. The instrument produces a friction coefficient for both the forward and backward movements of the stroke. For CSM linear nanotribometer, stroke frequency is in a range of 0.001-100Hz, stroke length is in a range of 10μm-1000μm with stroke length resolution of 250nm.

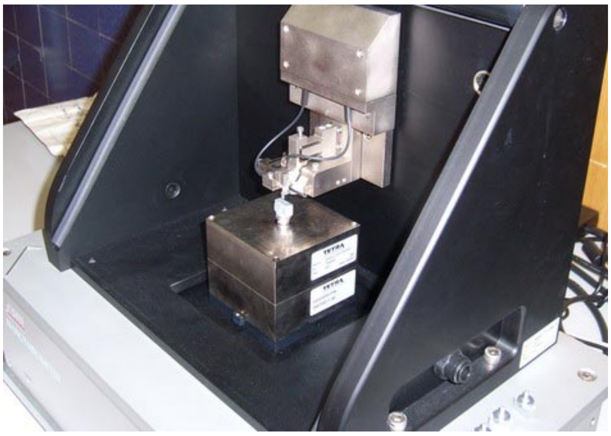

Figure 4. Linear reciprocating module

Nanotribometer device offers simple and efficient way of measurements of friction or adhesion at nano-scale. It belongs to a group of instruments for nano-scale investigations that require contact with a sample, so contact mode operation is used Ψ5β Figure 5. shows principle of working for CSM nanotribometer.

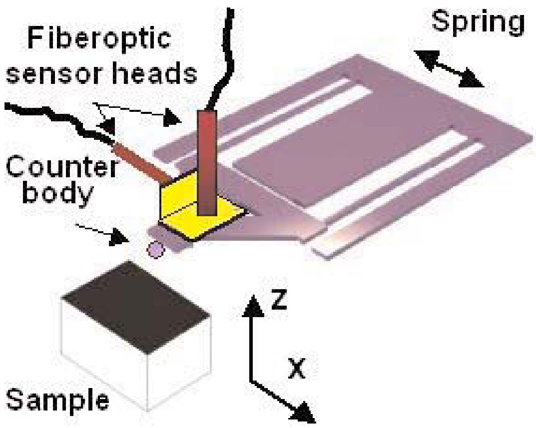

Figure 5. Schematic representation of nanotribometer contact geometry Ψ4β

The nanotribometer comprises characteristics that enable it to perform quantitative friction and wear investigations such as:

- Forces may change over a large range during the test.
- It directly measures the x-, y- and z- motions of the sample (precision piezo actuated movements).
- There exists a wide range of commercially available cantilever force sensors with which nanotribometer can operate (e.g. 0.1N/m up to 1000 N/m).
- Contact dimensions spans from 1 nm up to 10 μm.
- Precisely calibrated friction and wear measurements.
- Linear or Rotating sample movement.

- Automatic switch off at threshold coefficient of friction or total number of turns.
- Testing compatible with ASTM G99 & DIN 5032.
- Continuous wear depth measurement.

The wear phenomena and wear characteristics of reciprocating sliding wear are very important to investigate, whereas many real life cases can be comprehended by it. For instance, transition between fretting and reciprocating sliding wear has been investigated in order to determine the moment when structural damage occurs within material [5], [6]. It is also significant to connect in greater extent wear phenomena behaviour with surface topography and particle motion, based on what a wear model can be developed [7]. Instruments like nanotribometer that can be of assistance in these types of investigations are valuable equipment.

Application areas for which nanotribometer investigations can be applied varies broadly, such as: lubricants, oil additives, self-lubricating systems, semiconductor technology, protective coatings, optical scratch-resistant coatings, wear resistant coatings (TiN, TiC, DLC), paints and polymers or pharmacological (tablets, implants, biological tissue). Important information can be obtained by experiments at nano-scale in every of these areas and results that are published constantly confirm it, thus initiating series of further research projects aimed at dissemination of laboratory findings into a real world practice.

3.1 Tribological investigations of coatings

The mechanical properties of thin films and coatings cannot be measured accurately using techniques such as microhardness and tensile testing which were designed for bulk samples, so nanoindentation is starting to be applied more readily. Data obtained using nanotribometer can be further applied for optimization of these properties. Tribological behaviour of coatings applied to metal substrates, in general, is area of great interest for broad range of industries. Various models for wear under nanoindenting predefined mode determine tribological characteristics useful for further application.

Very useful indicator of surface uniformity on samples is mapping of material surface characteristics, what makes it possible to reveal non-uniform areas [8]. It can further optimize deposition conditions to produce high quality uniform thin films or can initiate further structural investigations of materials. Information regarding asperity interlocking, particle adhesion or stick-slip phenomena [9], can be obtained, in order to study in more details existent mechanisms of friction.

Through an enhancement of performance at the nanoscale and by seeking to extend product lifetimes and reduce energy consumption, a contribution to sustainability is achieved [10]. Through nano-scale tribological investigation of coatings characteristics at nanotribometer instrument, friction coefficient and wear rate can be measured, therefore enabling the establishment of relations between characteristics of wear and the structures of the surface. It also makes possible to model and predict wear and accordingly to improve it to wear resistant materials.

Investigations in this area are multidisciplinary and address multisectoral applications, from metal forming and machine tools to automotive engines, wind turbines and satellite mechanics. For instance, in scope of the 5^{th} Framework Programme (FP5) more than 40 nanotechnology-based projects were funded [11]. One such project cluster, comprised of six separate projects, was NANOTRIB project, [12] that represented joint work of 60 partners from 16 countries, in the field of nanoscale lubrication films and low-friction surfaces. Parts of this large project were devoted to the following areas: low-friction coatings; processing of structured hard coatings for microlubrication; development of nanocomposite coatings to improve competitiveness and conserve the environment; nanostructured coatings for engineering tribological applications; nanocomposite wear-resistant and self-lubricating PVD coatings for tools and components; surface layers for reduced friction and wear [13].

Some of very important technical and scientific results of this large tribo cluster, achieved in area of the development of advanced high-performance solid lubricant coatings were as follow [12]:

1. Relatively thick, 100-500 μm, solid lubricant coatings developed to be applied in machine-building industry.
2. Thin, 1-50 μm, solid lubricant coatings developed to be applied in aerospace and automotive industries.
3. Novel composite powder materials designed to be applied for fabrication of solid lubricant coatings possessing enhanced wear-resistance at temperatures up to 900°C in vacuum and in air. (Ni-Al base nano-powders, Fe-Alumina base nanocomposites, WC/Co nanocemented carbides).

Another area of coatings development and investigations is one of the tool coatings. Adequate tool surface modifications are vital to successful modern high-performance machining and metal cold forming operations [14]. The demands on the tool coatings are rising with the processing of new materials. Innovative tool coatings and new process designs are needed in order to meet all challenges imposed by modern market demands. A comprehensive investigation of the wear progress has been investigated for novel nano-multilayered coatings such as TiAlCrN/NbN that show greatly reduced wear rate compared to the other standard tool coatings [15].

Materials production focuses on advanced materials, coatings and production technologies. Steel based materials and composite materials are the two main categories in this sector with a huge level of investments. Area of research comprises strength and ductility performance, adhesion and joining of coated materials, nanotechnology and polymer / metal matrix systems etc.

Emerging area of R&D interest are organic coatings. For instance, polymeric coatings to aluminum alloys are very relevant for a wide variety of application areas such as construction, automotive and aerospace applications. Adhesion mechanisms and local processes at organic coating-bulk material inter-phases determine the behaviour and macro characteristics of these systems. Inorganic–organic hybrid materials are attracting a strong scientific interest mainly for their outstanding inherent mechanical and thermal properties [16]. These novel protective coatings are to be investigated from various aspects and nanotribometry instruments are of valuable assistance. The overall objective is to deliver innovative coating and surfacing techniques and associated modelling tools, to industrial partners for them to integrate tribology as main design criteria.

The wear occurring at very low normal loads and in very small contacts is of prime interest to the field of nanotribology [17]. New test procedures and new investigation methods are to be established and utilized in such a way to enable understanding of tribological processes at nano/micro level in more extent and for improvement of existing procedures. Understanding tribological behaviour at nanoscale will lead to control of tribological functions at macroscale. It is obvious, due to all previously stated, that nanotribometry methods need to be applied in order to examine the influence of different process parameters and to efficiently investigate these novel structures.

4. CONCLUSIONS

Tribological behaviour of a material at nanoscale has to be studied with rather different set of observed characteristics compared to the previous traditional approach. As such, it is of a great importance to investigate phenomena and manipulation of matter at the nanoscale. Application of such a knowledge can and will lead to introduction of new forms of manufacturing, new products and services. Also, there are number of possible environment related issues that nanosciences promise to resolve in close future.

Theoretical studies on atomic scale friction still need to be acknowledged from practical aspects. Nanostructures created between the surfaces in relative motion are crucial for energy dissipation mechanisms. The future trends of research in this area anticipate possibilities of engineering frictional surfaces in such a manner that they would satisfy predefined conditions regarding friction coefficients.

REFERENCES

[1.] *Bhushan B. (ed.),* Nanotribology and Nanomechanics, Springer, 2005.

[2.] Friction, Lubrication, and Wear Technology, Volume 18, ASM Metals Handbook, ASM International, 1992.

[3.] *Ivkovic B., Rac A.*, Tribology (in Serbian), Yugoslav Tribology Society, 1995.

[4.] *CSM bulletin*, Tribology at Nanometer scale, http://www.csm-instruments.com

[5.] *Chen G. X., Zhou Z. R.*, Study on transition between fretting and reciprocating sliding wear, Vol. 250, Wear, 2001.

[6.] *I. Samerski* (Sp),et al., Influence of the Surface Topography on the Transition between High and Low Wear Regimes under Multidirectional Reciprocating Sliding, International Symposium on Friction, Wear and Wear Protection, 9-11 April, 2008., Germany

[7.] *Stachowiak G.W., Batchelor A.W.*, Fretting and Minor Wear Mechanisms, Engineering Tribology, 2006.

[8.] *Bhushan B. (ed.),* Springer handbook of nanotechnology, Springer, 2004.

[9.] *Bhushan B., et al. (ed.),* Applied Scanning Probe Methods, Springer, 2005.

[10.] *L. B. Lave,* Lifecycle/sustainability implications of nanotechnology. In: Societal Implications of Nanoscience and Nanotechnology, ed. by M. Roco, W. S. Bainbridge (Kluwer, Dordrecht 2001)

[11.] *Živić F.*, Nanotribometer Area of Application, Tribology in industry, vol. 29, No. 3&4, 2007.

[12.] NANOTRIB cluster, http://www.vito.be/nanotrib/

[13.] *Schulte J.*, Nanotechnology, Global Strategies, Industry Trends and Applications, John Wiley & Sons Ltd, 2005.

[14.] *Warnke C.* (Sp),et al., High Performance PVD-Coatings for Tools, International Symposium on Friction, Wear and Wear Protection, 9-11 April, 2008., Germany

[15.] *L. Ning, S.C. Veldhuis, K. Yamamoto*, Investigation of wear behaviour and chip formation for cutting tools with nano-multilayered TiAlCrN/NbN PVD coating, International Journal of Machine Tools and Manufacture, Vol.48, 2008.

[16.] *Girardi F.*, et al, Inorganic–organic hybrid materials with zirconium oxoclusters as protective coatings on aluminium alloys, Progress in Organic Coatings, Vol.62, 2008.

[17.] *Achanta S., Drees D., Celis J.P.*, Friction and nanowear of hard coatings in reciprocating sliding at milli-Newton loads, Vol. 259, Wear, 2005.