The use of optical microscopy to evaluate the tribological properties

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Tribology is an important method for evaluating the coefficient of friction and wear of friction pairs of technical materials. The most commonly used modes are "pin on disc", resp. "ball on disc". Tribology can simulate the stress of two objects (the friction between the objects) under the real conditions. The output of the tribological test is a specific value of the coefficient of friction and wear rate. For a comprehensive evaluation of tribological properties is used the optical microscopy - to evaluate the size of wear of the pad (groove width) and of the pin (loss of material of the ball or roller). The use of modern sophisticated equipment allows to evaluate the coefficient of friction and wear also in various environments, such as in the process fluids.

Keywords: tribology, coefficient of friction, optical microscopy, process fluids

1 Introduction

Tribology evaluates the properties that affect the interaction of the surface, environment and the bodies during their relative motion. It includes processes of interaction in the boundary layer between solid, liquid and gas elements. The main goal of tribology is to ensure that relative movement of the two surfaces was carried out with the minimum loss of energy and materials. The tribological properties mainly describes the coefficient of friction and wear, which depends mainly on the type of friction and wear mechanism. [1, 2 and 3]. When examining the effects of friction and speeches we look at a system consisting of two bodies and their contact surfaces and a substance that is between contact areas and close surroundings, such as the tribological system.

1.1 The mechanism of friction

Friction is defined as resistance to the relative motion of two bodies in their contact area. Friction force F depends on the friction coefficient μ and the loading force L [1, 4]. The description of friction and the introduction of this concept was first dealt by Coulomb (1799) and today is a fundamental relationship known as Coulomb's law:

$$\mu = \frac{F_t}{F_p}, \tag{1}$$

Where:

F_t [N] the frictional force acting against the direction of movement,
F_p [N] the pressing force acting perpendicular to the direction of movement,
μ coefficient of friction.

For the presence of lubricant the friction can be divided into (Fig. 1):

- physical dry friction – between surfaces is not a gas or liquid and they are covered with a chemical compound (friction in vacuo),
- technical dry friction – surface can be coated with oxides, gases or vapors,
- mixed friction - there are occasional touches of micro-inequality, lubricant is present between surfaces,
- fluid friction – surfaces are during the movement completely separated by the continuous layer of a liquid lubricant, or other liquid medium [2, 5].

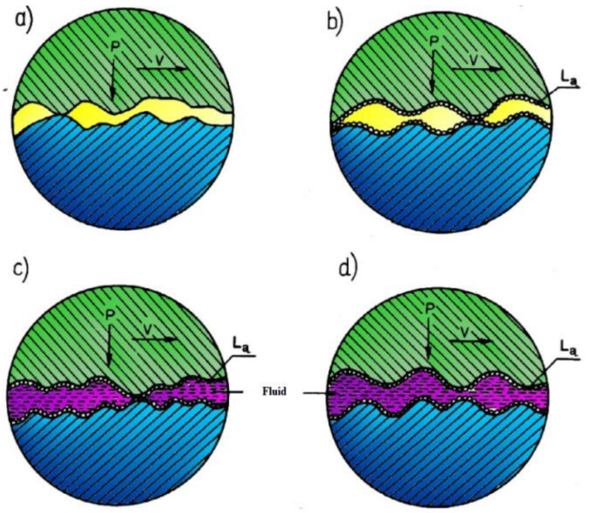

Fig. 1 *The friction according to the presence of lubricants, a) physical dry friction b) technical dry friction c) mixed friction d) fluid friction, La – oxide layer [2]*

2 Effect of production technology on the surface layer

From a theoretical analysis of the cutting process and on the basis of experimental research can be concluded that the cutting conditions have a significant influence on the properties of the surface layer. Whether it is the cutting speed, type of tool material, finishing operation or the change the type of used lubricant. The lifetime of specific components depends in the first place on local properties of the material in the most stressed point and not on the average performance of the whole cross-section.

Each technological operation causes a redistribution of residual stresses. Size of the affected volume is determined not only by prezent of thermal field (its development) and plastic deformation, but also by changes in the phase composition. An important factor dutiny the machining is the time of action of the effects of cutting conditions and speed changes occurring conditions. It is strongly manifested, for example dutiny the sanding; when heating is very rapid and short-term, the rate of heating and cooling time take place under the extreme conditions. Although the quality of the surface layer has the greatest influence of the last operation; may inappropriately chosen sequence of operations may remain in the surface layer maintained influence of the previous operations. [6]

In addition to machining parameters such as cutting speed, feed and depth of cut plays an important role the chemical composition of tool and workpiece (which largely affects the thermal conductivity and therefore heat redistribution between the workpiece, chip and tool), tool geometry, heat dissipation and lubrication. [7, 8]

Use of a lubricant during a machining process reduces cutting forces (lubricating effect) and transfers heat from the surface (cooling effect). Directly therefore has concluded that lubrication causes a reduction in the size of the residual stress, and reduces the depth of the affected area. [9, 10]

Tribology is of growing importance for producers gain a better appreciation of the impact on the performance of a specific product mainly for his lifetime. The development of modern high-strength materials, modernization of methods of measurement in the field of material sciences and long experience with the operation of advanced technological systems show that the surface layer significantly affect their durability and reliability. [11] The data from the tribological tests can be crucial for optimizing the design of a part or assembly, which is the process of surface finishing, coating composition or lubrication.

3 The use of the optical microscopy and mechanical profilometer

The use of light-optical microscope allows to observe and analyze the microscopic objects and structures in reflected light at magnifications from 25x to 1000x. Preparation of samples for analysis at the optical microscope observation in reflected light occurs first grinding and then polishing. The contrast of the images is obtained based on the individual structural reflexivity, different phases or due to the surface topography. The intensity of reflected light is proportional to $\cos\varphi$, where φ is the angle between the sample surface and the incident light beam. [12]

Recording of images from a light optical microscope is obtained by CCD camera. The scanned data can then archive, analyze and modify by the software. The goal of data software analysis is the processing of visual information, elimination of random errors and extraction of typical features characterizing the image. [12, 13]

Optical microscopy allows very fast display structures using the various contrast methods, e.g. phase contrast, polarization, fluorescence, Hoffman modulation contrast or Nomarski differential interference contrast. [14]

The tip of mechanical profilometer DektakXT ™ is in direct contact with the sample. Compressing force during the experiment can be adjusted (ranging 1 to 15 mg). The load must be selected according to the type of the sample, to prevent the mechanical damage (scratching) of samples if the sample is soft and the force disproportionately large. During the measurement the sample is placed on a substrate (Fig. 4) and it is in direct contact with the tip. Unevenness on the surface of the sample are registered by the tip, which performs vertical movement. The sample is moved relative to the stationary pin. For some profilometers it is the opposite - the sample is in place and stylus moves in the vertical and horizontal directions (this option is less frequent).

Mechanical profilometer scan in the contact way the shape of solid surfaces by diamond tip the size of few micrometers, thereby it is possible to study the surface morphology on the horizontal scale size hundreds of micrometers to tens of millimeters, with a vertical resolution of one nanometer. It is thus possible to determine for example; surface roughness, thickness of the non-transparent layer, the shapes of the etched structures, profiles of inclined deficits and so on.

4 Experimental arrangement

The basis of tribological measurement is the testing by using method ball-on-disc. Measurement involves the injection of a fixed attachments of the test piece ("Ball") in the form of ball from the chosen material by predefined power to the disc (of tested sample). After reaching the selected load the disc table starts to spin and the body remains motionless. Part of the measuring system is a sensor that allows measurement of the load and normal friction force between the body and the disc during the experiment.

The coefficient of friction was determined using the tribometer Cetra UMI Multi - Specimen Test System (Fig. 2) and profile groove after tribological test was evaluated by mechanical profilometer Dektak - XT (Fig. 4) from BRUKER.

***Fig. 2** CETR UMI Multi-Specimen Test System*

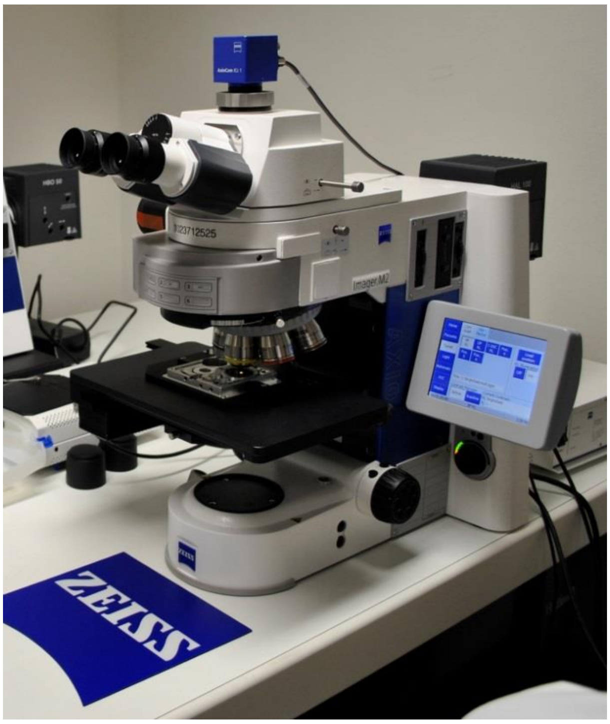

***Fig. 3** Light optical microscope*

Direct light optical microscope (LOM) Zeiss AXIO Imager M2 with a fully motorized stage configuration for observations in reflected light (see Fig. 3).

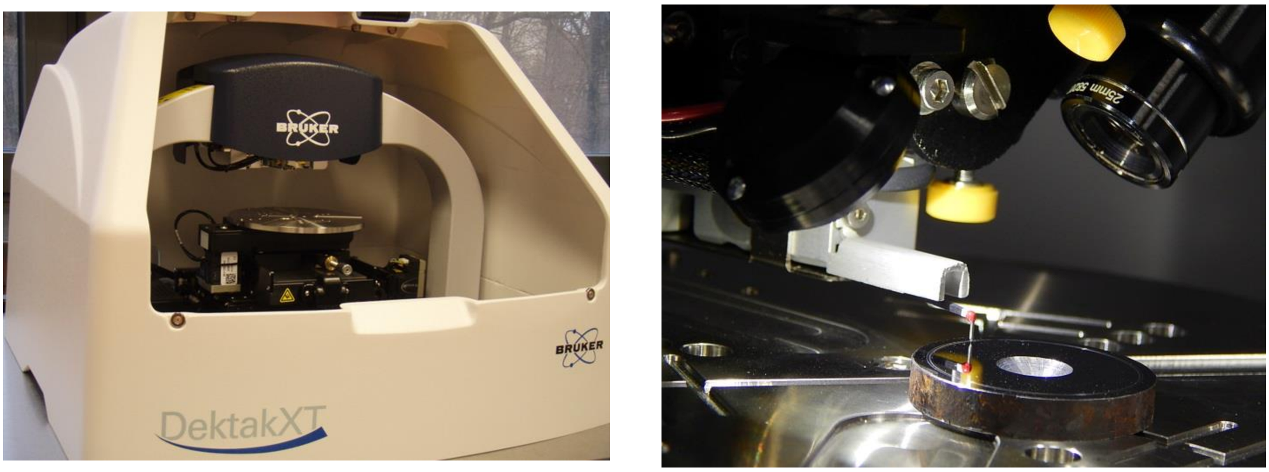

Fig. 4 *Mechanical profilometer Dektak – XT*

5 Results of experiment

Tribological testing was performed using a ball made of Si_3N_4 with diameter of 6,350 mm, with a constant load of 10 N at room temperature. The material of used disc (tested sample) was steel ISO 683/11-70 with polished surface and roughness of Ra 0.01µm. The radius of the circle over which the "Ball" body was moving was 13 mm and the friction coefficient measurement was carried out using a 5% solution of process fluid volume 100 ml.

The research was conducted using a 5 % solution of five different process fluids. Study of tribological behavior of process liquids during the tribological experiment is shown in Fig. 5. Furthermore, the comparison with dry friction is shown in Fig. 6 which shows the influence of cutting fluids on lubricating ability during the tribological experiment.

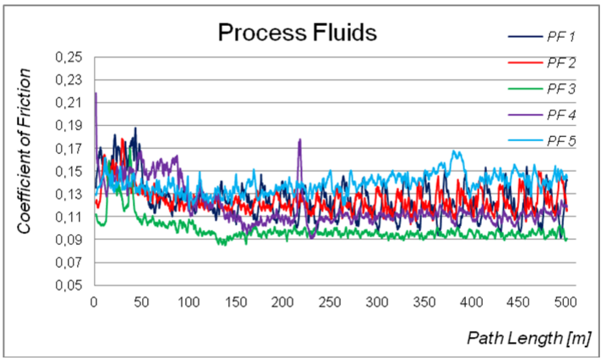

Fig. 5 *Coefficient of fiction of process fluids 1 – 5*

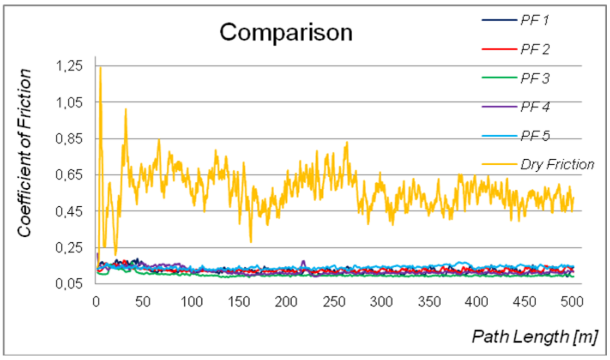

Fig. 6 *Comperison of coefficient of friction of process fluids 1 – 5 with dry friction*

On Fig. 7-11 are results from optical microscope. The results for process fluids are shown gradually 1, 2, 3, 4 and 5, the size of wear of the balls after tribology. On the next picture is scanned profile by the mechanical profilometer, which provides information about the depth and width of the groove.

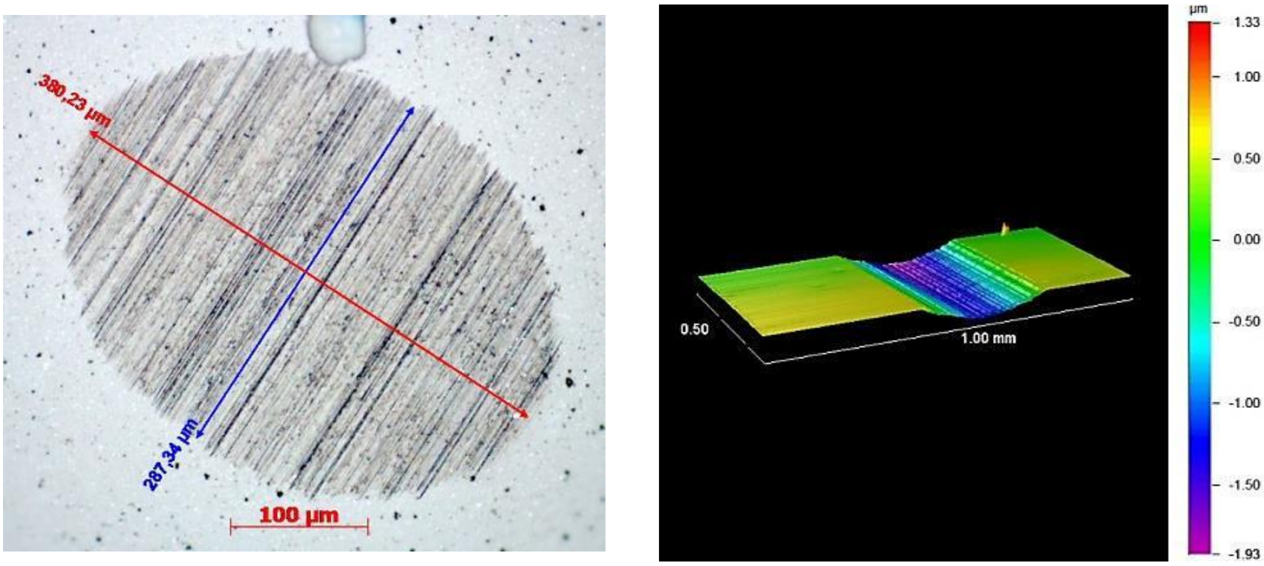

Fig. 7 *Evaluation of wear of the ball made by an optical microscope and 3D image of the profile groove made by a mechanical profilometer - PF 1*

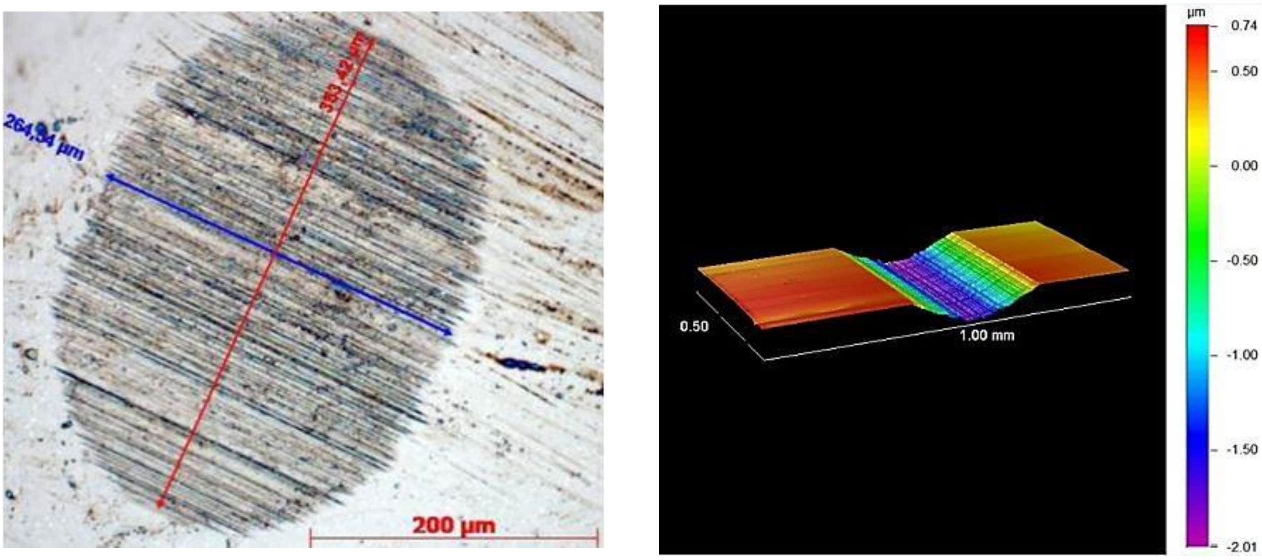

Fig. 8 *Evaluation of wear of the ball made by an optical microscope and 3D image of the profile groove made by a mechanical profilometer - PF 2*

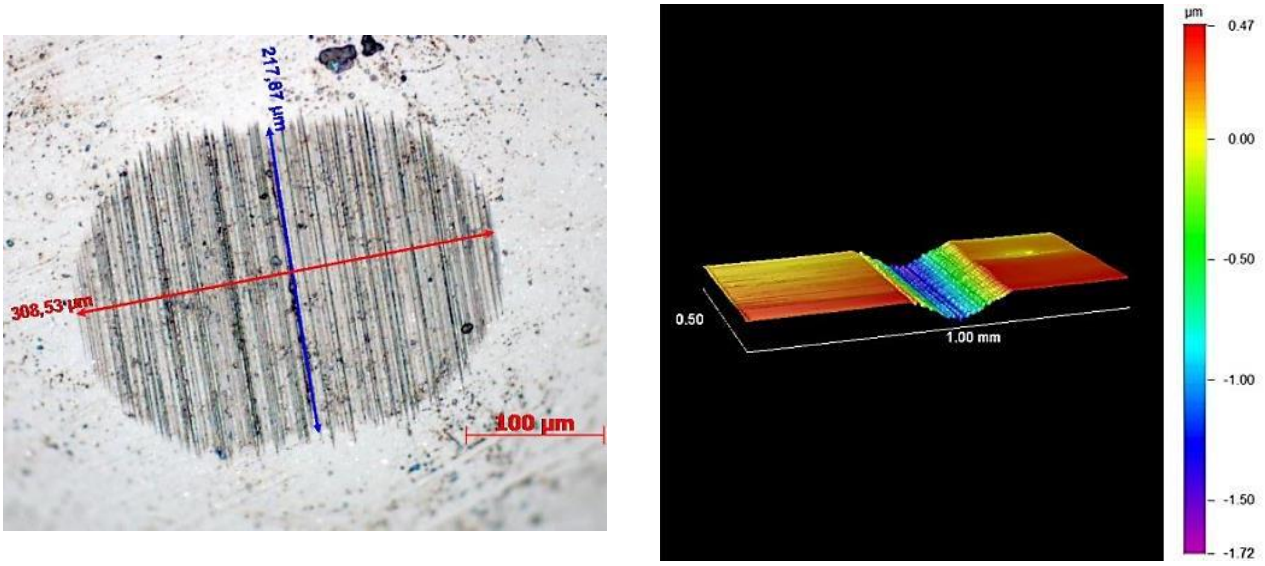

Fig. 9 *Evaluation of wear of the ball made by an optical microscope and 3D image of the profile groove made by a mechanical profilometer - PF 3*

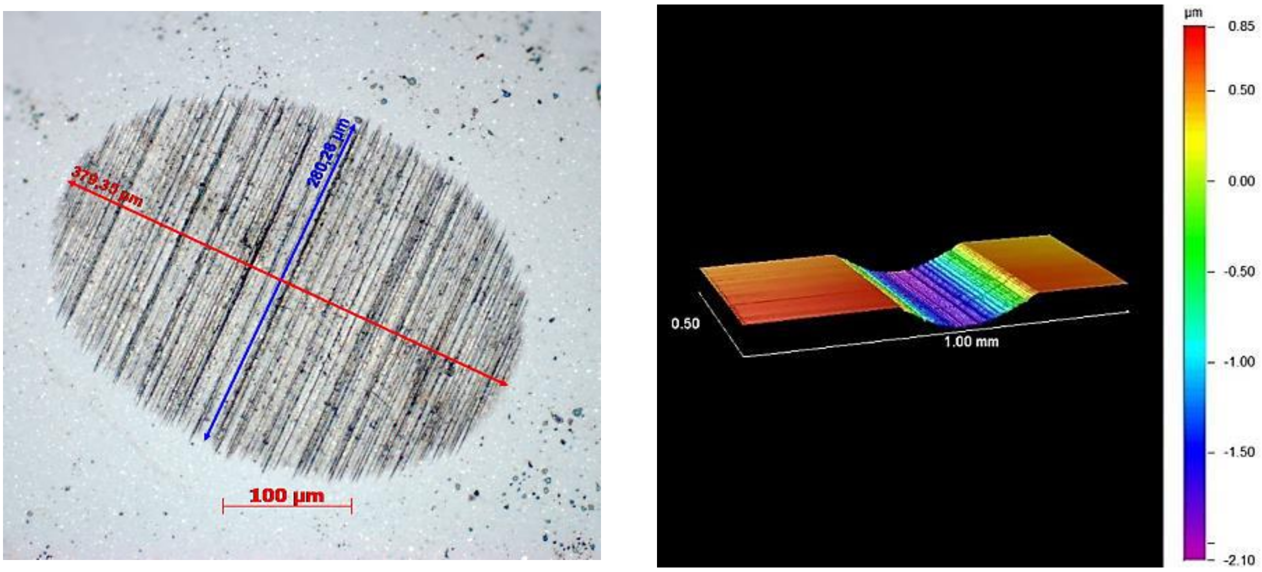

Fig. 10 *Evaluation of wear of the ball made by an optical microscope and 3D image of the profile groove made by a mechanical profilometer - PF 4*

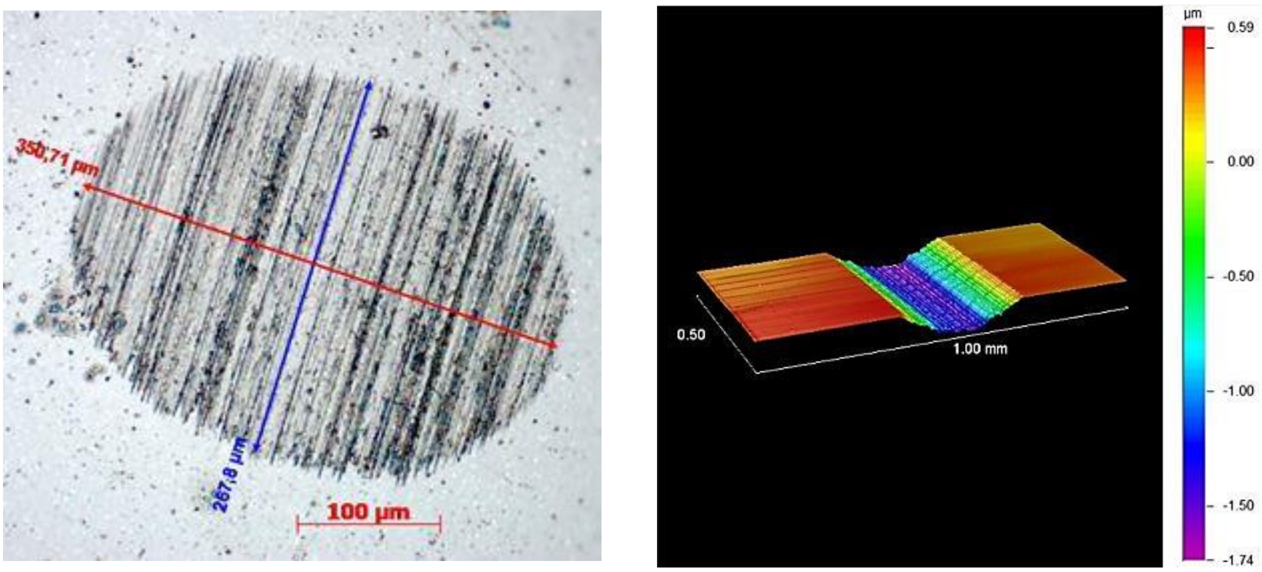

Fig. 11 *Evaluation of wear of the ball made by an optical microscope and 3D image of the profile groove made by a mechanical profilometer - PF 5*

6 Conclusion

Optical microscopy allows to obtain information about the degree of wear of the balls and the groove width of removed material under defined experimental conditions. The relevant software gives the possibility to measure differences in wear of ball using different process fluids. PF 3 showed the best results, where the measured profile width of the groove was about 280 µm and wear of the ball was about 300 µm. This fluid has good lubricating ability.

By mechanical profilometer was this fact confirmed and by using a 3D imaging of the profile groove was obtained an information about the volume of removed material from the substrate. For PF 3 was measured volume 7.71×10^{-5} mm³, rounding of the tip 2 µm, range was 6.5 µm, and load 5mg.

The experiments have shown the possibility of using optical microscopy and mechanical profilometer for evaluation of tribological properties of friction pairs under the controlled environment. Experiment enabled an optimal choice of process fluids for industrial use.

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