LATERAL FORCE UNIT: NEW POSSIBILITIES FOR MECHANICAL CHARACTERIZATION OF MATERIALS

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Introduction

In the last half of the XX$^{\text{th}}$ century and the first years of XXI$^{\text{th}}$ century a large amount of methods for the determination of mechanical properties of materials was developed. The advances in experimental techniques such as the nano-indentation [1], atomic force microscopy [2], and nano-tribology tests [3] have made possible the study of micro- and nano-scale mechanical properties of materials. However, the necessity of more and more correct determination of mechanical properties at the micro- and nano-scale remains and becomes increasingly urgent every day.

Thus, the new lateral force application technique namely Lateral Force Unit (LFU) has been recently constructed by the ASMEC GmbH for the extension of possibilities of normal spherical nanoindentation. This tool, which is installed on the stage of a nanoindenter, allows to apply a lateral force to a sample during standard nanoindentation. In the result, lateral force-displacement curves with high resolution can be measured. The lateral force and displacement resolutions of the LFU are less than 1µN and 1nm respectively. The construction and the operation principle of the LFU together with the nanoindenter UMIS 2000 (CSIRO, Australia) is presented in detail in [4].

It was established that at least three new possibilities for mechanical characterization of materials can be realized by the use of the LFU. In this paper the detailed description of one of these possibilities and the basics of the other two are presented.

Investigation of micro-scale friction behaviour of materials

The determination of the friction behavior of materials is one of the most important tasks of investigation of mechanical properties of materials. The knowledge of the friction behavior is needed both for the optimization of machinery and for the understanding of fundamental mechanisms of adhesion.

A normal load of 60mN has been applied to a DLC-film of 295nm thickness on a silicon substrate by means of the spherical diamond indenter of 10.5µm radius (see Fig.1). All measurements have been made in the elastic region of normal indentation. The LFU measurements have been done in such a way that the lateral force has been applied during the normal hold period after the normal loading, i.e. at constant maximal normal force (see Fig.1). In the result, the lateral force–displacement curve as average of 15 measurements has been recorded (see Fig.2).

The description of the behaviour of this latter force–displacement curve is the following:

1. During the initial lateral hold period the lateral force is zero. The normal load is increased to its maximal value of 60mN and kept constant afterwards.
2. At the beginning of lateral loading the lateral displacement is not observed due to the adhesion of indenter on the sample surface. Thus, the ***static (sticking) friction coefficient*** can be calculated as the ratio of maximum lateral force F_L of this part of curve and the normal force, which has been applied by the nanoindenter, i.e. $\mu_{static} = F_L/F_N$. Thus, for a DLC-film with thickness of 295nm the static friction coefficient against diamond is equal to 0.044. Probably, during this period two mechanical processes take place. The first is the bending of the UMIS

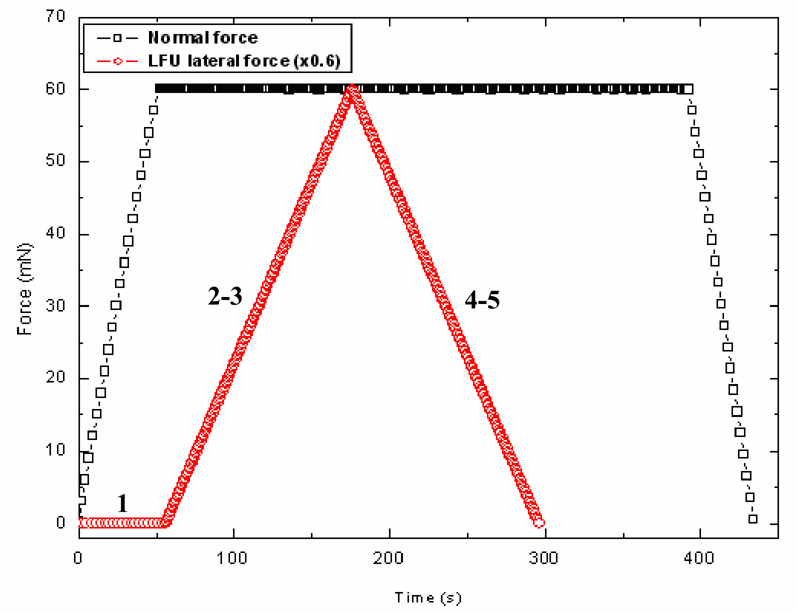

Fig.1. UMIS normal (the black line) and LFU lateral (the red line) force cycles. The normal force increases linearly within 55s up to the maximal value of 60mN (**1**). When the maximal value of the normal force is achieved the LFU lateral force is immediately started by hand. The LFU lateral force increases within 120s linearly up to 100mN (**2-3**) and decreases within 120s linearly to zero (**4-5**).

indenter shaft in the result of the adhesion and the LFU lateral force action. The second is the elastic deformation of sample predominantly to the direction of the lateral force action.

3. At further lateral loading an approximately constant lateral force is observed while lateral displacement takes place. The indenter slides along the surface with only elastic deformation. The lateral displacement reaches maximum value of 1.22µm.
4. At the beginning of lateral unloading the indenter sticks on the surface. Thus, the maximum lateral displacement is constant until the lateral force in the opposite direction is large enough to finally overcome the sticking friction. Probably, during this period the bending of the UMIS indenter shaft changes in the opposite direction.
5. At further lateral unloading an approximately constant lateral force is observed while reverse lateral displacement takes place. The indenter slides towards the zero position. The bending of the indenter shaft itself prevents reaching the initial zero position.

Thus, the combination of normal spherical indentation by a nanoindenter and lateral force-displacement measurements by the LFU allows determining the micro-scale friction behaviour between the indenter and the sample materials with high lateral resolution. As a result, the possibility of static friction coefficient determination in the micro-scale range is realized by the LFU.

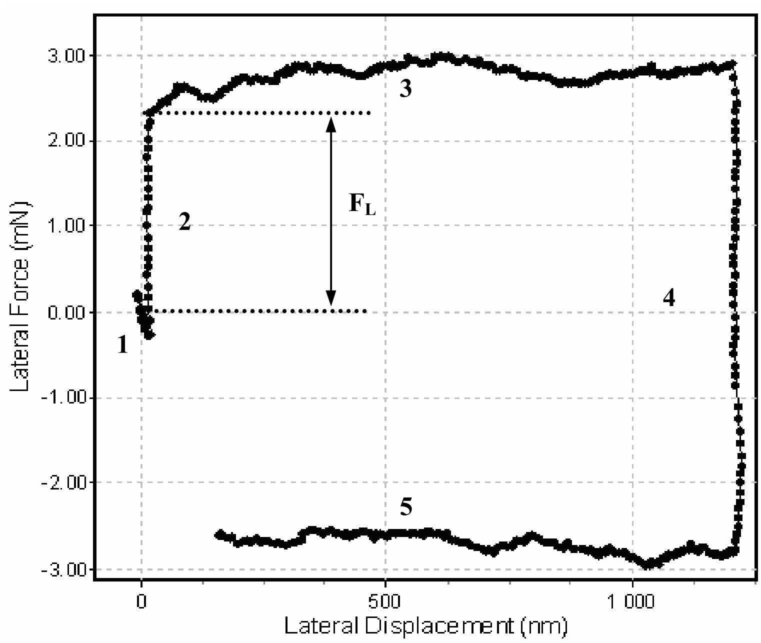

Fig. 2. Lateral force – displacement curve. The numeration of the parts of curves corresponds to the

Detection of onset of plastic deformation

The detection of the onset of plastic deformation allows determining another important mechanical property namely the yield strength. One of the most effective and widely used nondestructive methods of detection of plastic deformation onset and determination of critical force of this onset is the loading–partial unloading method for spherical indentation, which was developed by J.S. Field and M.V. Swain and presented in detail in article [5]. However, on the one hand not all of the depth-sensing submicron indentation techniques can be used for the application of a normal force with a loading–partial unloading cycle. On the other hand the correct determination of the yield strength of a hard film on the soft substrate is not an easy task by means of standard nanoindentation because the plastic deformation of the substrate may take place before the plastic deformation of the coating. But by the lateral force application to coated materials the fields of stresses and deformations can be redistributed in such a way that the plastic deformation in the coating can become possible before than in substrate.

Failure detection

Brittle materials are widely used in fabrication. But they are highly vulnerable to fracture from concentrated loads. Therefore, the investigation of fracture behavior of brittle materials is one of the most important tasks of mechanical testing. The formation of cracks can be detected by direct methods such as, for instance, scanning electron microscopy (SEM) or atomic force microscopy (AFM). The nanoindentation is an indirect method of the crack determination by means of the detection of pop-in effects in the normal load–displacement curves [6]. But in many cases the nanoindentation does not allow to detect these pop-in effects or the interpretation of these effects is ambiguous.

The indentation fracture was first studied in detail by Hertz. He found that by means of the hard spherical indenter the cone crack is formed near the edge of the contact cycle where the tensile stresses are the greatest [7]. The use of lateral force by the LFU allows increasing the tensile stress near the edge of the contact cycle behind the indenter. Therefore, the failure namely, most probably, the cone crack can be generated and detected.

Conclusions

The combination of lateral force-displacement measurements by the Lateral Force Unit and normal spherical indentation by a nanoindenter allows to estimate mechanical properties of materials more comprehensively. This was shown by the example of the investigation of the micro-scale friction behaviour between the indenter and a sample material.

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