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NANO-HARDNESS OF THE MATERIAL OF THIN LAYERS OF THE INJECTOR TIP DEPENDING ON THE DEPTH UNDER THE PRECISLY FINISHED CO-OPERATING SURFACES

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Abstract

In this paper, the authors present the results of experimental studies of the nano-hardness and Young's modulus of the injector spray pattern body and needle (the tip of the injector). The nano-hardness of a thin-layer of precisely finished co-operating surfaces was tested according to the depth below the surface of the sample (deep into the material).

The quality of precisely finished surfaces of a fuel infector has a very large impact on the proper operation of a diesel engine. Both, the needle and the body of the injector spray pattern, are individually adjusted and lapped to maintain the proper gap between them. The gap between the needle and the injector tip body affects the proper dosage and quality of the sprayed fuel. Impurities in the fuel are of the same order of magnitude or even greater than this gap. Hard particles that penetrate between the side surfaces of the needle and body of the injector tip could result in scratching, which generate leaks and drops of injection pressure, increased fuel consumption, poor spraying of fuel, leaking of fuel to the lubricating oil and reduction of its operating properties. The hardness of the precisely finished surfaces of the injector is essential in the process of wear of these surfaces.

The aim of the study was to determine the hardness and Young's modulus of thin layers of precisely finished co-operating surfaces of injector tip and estimation of the thickness of these layers.

The nano-hardness measurements were made with the Hysitron TI 950 TriboIdenter, where the test is conducted using a nano-indenter with a mechanical method. The device allows selecting from several to several dozen of measurement points and performs automatic measurement of nano-hardness and Young's modulus in the indicated locations.

The study concerns the tip (body and needle) of the non-used Bosch DLLA 160 S 1305 injector. The presented results can be used to develop some new methods of coating the co-operating surfaces with the hard thin layers, e.g. the use of titanium in order to decrease wear and increase scratching resistance.

***Keywords**: nano-hardness, Young’s modulus, nano-identer, injector tip nozzle, injector spray pattern, injector tip needle*

1. Introduction

The great progress in the manufacture of measuring devices at the micro- and nano-scale, such as micro-hardness testers, atomic force microscopes, nano-indenters, significantly influenced the development of research on micro- and nano-properties of materials, including the hardness and surface topography 3D [1, 4-8]. The indentation process is multifaceted and is now being considered in the fields of mechanics of continuous mediums, studies on the behaviour of individual dislo-cations under the influence of small loads, etc. [8]. The mechanism of the formation of micro- and nano-indentation is related to the motion and interaction of dislocations and interstitial defects [2]. Nano-indentation is now a widely used method to evaluate the mechanical properties of solids [3, 4].

Nano-indentation made on an atomic force microscope (AFM) has many advantages. In addition to execution of micro-cavity, the same device can be used to determine its properties. However, the nano-hardness tests with the atomic force microscopes have also disadvantages, e.g. a very small normal force or completing measurements one after the other. This problem can be avoided by using the nano-indenters.

The nano-identers are characterized by: high automation of the measuring process, possibility to set from a few to several measurement points, loads are much greater than for AFM, complete instrumentation of a measuring process and also tips with a radius of several tens of nanometres. These features give the nano-indenters an advantage over the atomic force microscopes.

The nano-indentation can be also carried out on scanning electron microscopes and transmission electron microscopes.

This research was conducted with the Hysitron TI 950 TriboIdenter. The basic parameters of this nano-indenter are [9]:

- optics specifications:
  - normal field of view – max: 625 μm × 550 μm, min: 28 μm × 22 μm,
  - magnification – optical: 20X, digital zoom: 0.5X-11X, effective: 10X-220X,
  - X and Y axis: Z-Axis:
  - travel distance: 300 mm x 300 mm, – 50 mm,
  - micro-stepping resolution: 50 nm, – 3.1 nm,
  - encoder resolution: 100 nm,
  - maximum translation speed – 30 mm/sec, – 1.9 mm/sec.

The aim of the study was to determine the hardness and Young's modulus of thin layers of precisely manufactured surfaces of the fuel injector tips spray patterns and assessment of the thickness of these layers.

The study considered the new and the used Bosch injector, labelled by number DLLA 160 S 1305. The quality of surfaces of the injector tip is very important for the proper operation of a diesel engine. Both, the needle and body of the spray pattern, are individually prepared. The gap between the needle and the body influences on the quality of fuel spraying. Impurities in the fuel are of the same order of magnitude and even more as the gap. Ingress of hard particles between the side surfaces of the needle and the body of injector tip may cause scratching, which generates leaks and a drop in injection pressure, increased fuel consumption, poor spraying of fuel, the admission of fuel to lubricating oil and reduction of oil operating properties. The hardness of such co-operating surfaces has a significant impact, in the aspect of wear of these surfaces.

The presented results can be used to develop some new methods of coating the co-operating surfaces with the hard thin layers, e.g. the use of titanium in order to decrease wear and increase scratching resistance.

2. Experimental studies

The nano-hardness and Young's modulus tests of thin layers (depending on depth below the surface) were carried out for injector tips needle and body. The view of injector tip needle and body is shown in Fig. 1a, while finally prepared samples are shown in Fig. 1b. The samples were embedded with the epoxy resin and polished on one side. The prepared samples were installed on the stage of the nano-indenter and properly placed (see Fig. 2a). A dozen of measurement points were selected (see Fig. 2b).

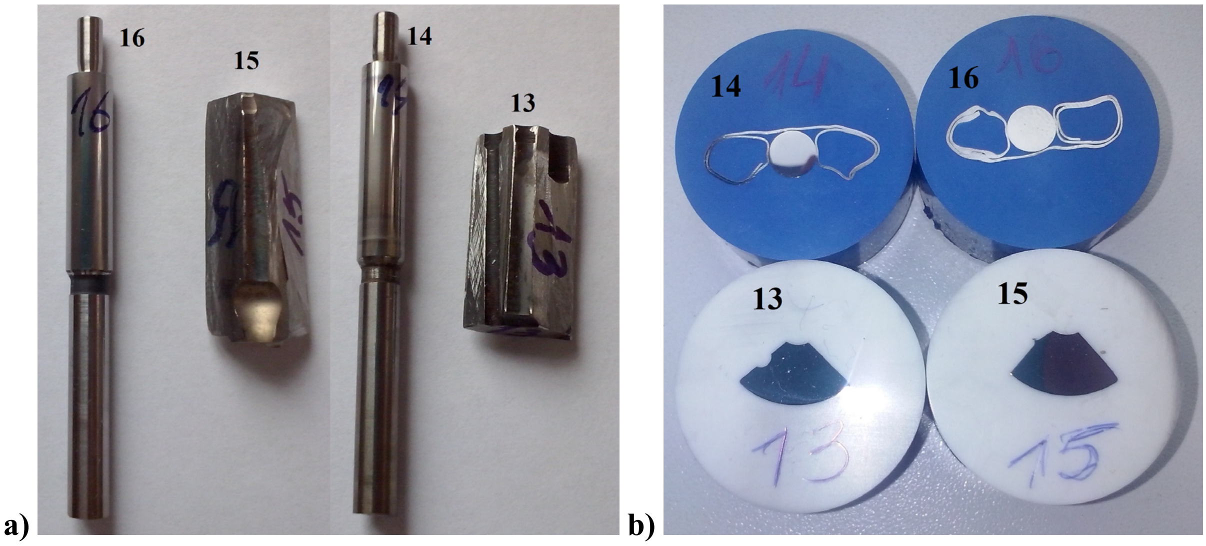

Fig. 1. The investigated parts of DLLA 160 S 1305 injector: a) the view of the injector needle and body, b) the corresponding prepared samples; 16 – new injector tip needle, 14 – used injector tip needle, 15 – new injector tip body, 13 – used injector tip body

The automatic measurement in 20 locations lasted about 2 hours. After the test, the cumulative graphs from each position, were obtained, which are shown in Fig. 3. The graphs showing the differences in elastic and plastic deformations while pressing (squeezing, loading) and lifting-off (unloading) the tip of the indenter.

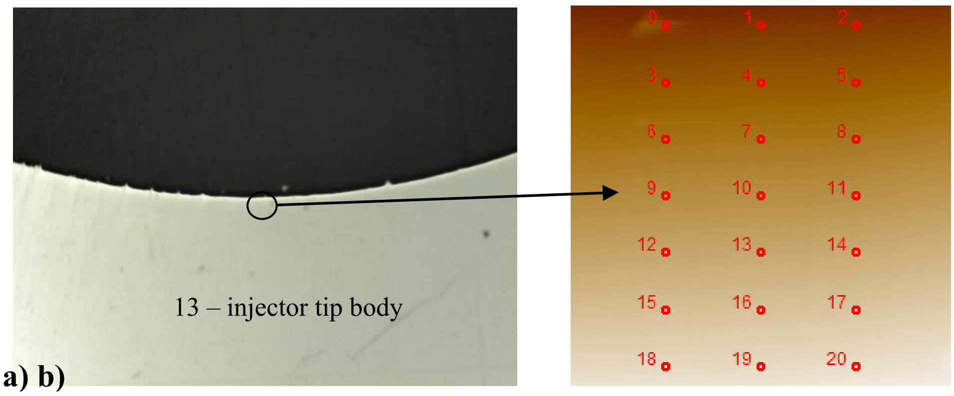

Fig. 2. The view of the investigated sample: a) an enlarged view – injector tip body (used), b) distribution of the measuring points

The next stage of this study, was to use the received data to determine nano-hardness and Young's modulus of investigated samples. It should be noted, that when measuring at random locations on the surface of the sample, we can get some results, where surface material defects occur. Such findings should be rejected.

The individual nano-hardness and Young's modulus values for each location and also their mean values for sample, are shown in Fig. 4.

The same course of studies was carried out for remaining elements of the injector tips, i.e. the second body of the new injector tip and also for two needles (new and used) of the injector tips.

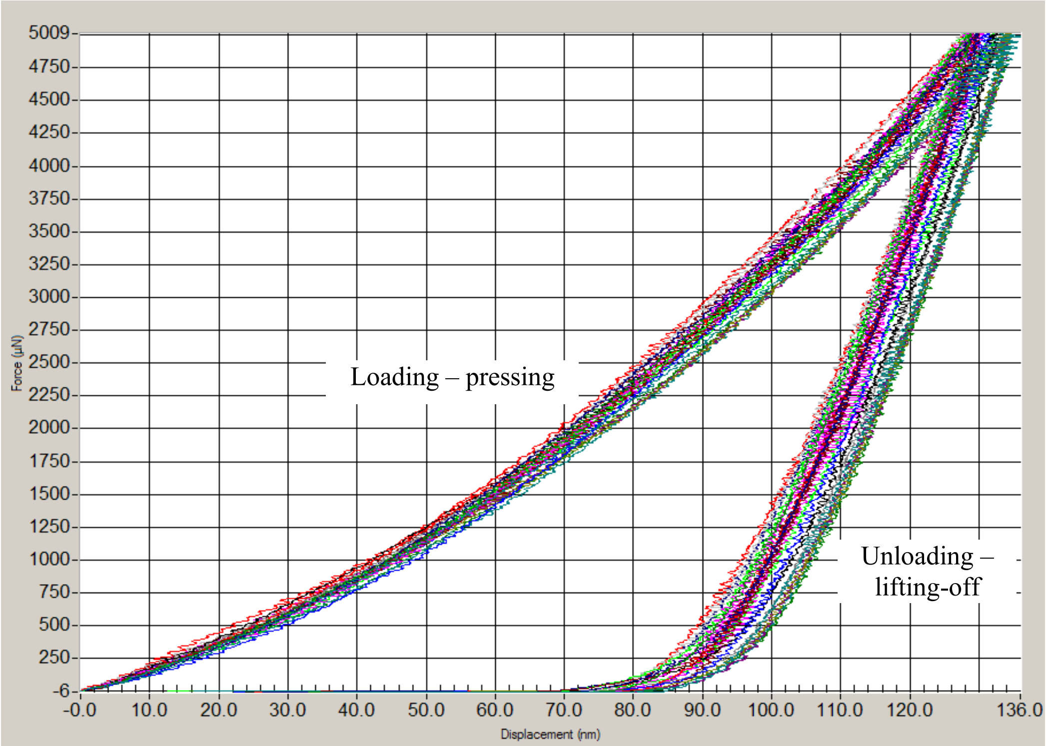

Fig. 3. Exemplary diagram showing the surface deformation during loading and unloading – sample of the injector tip body (used)

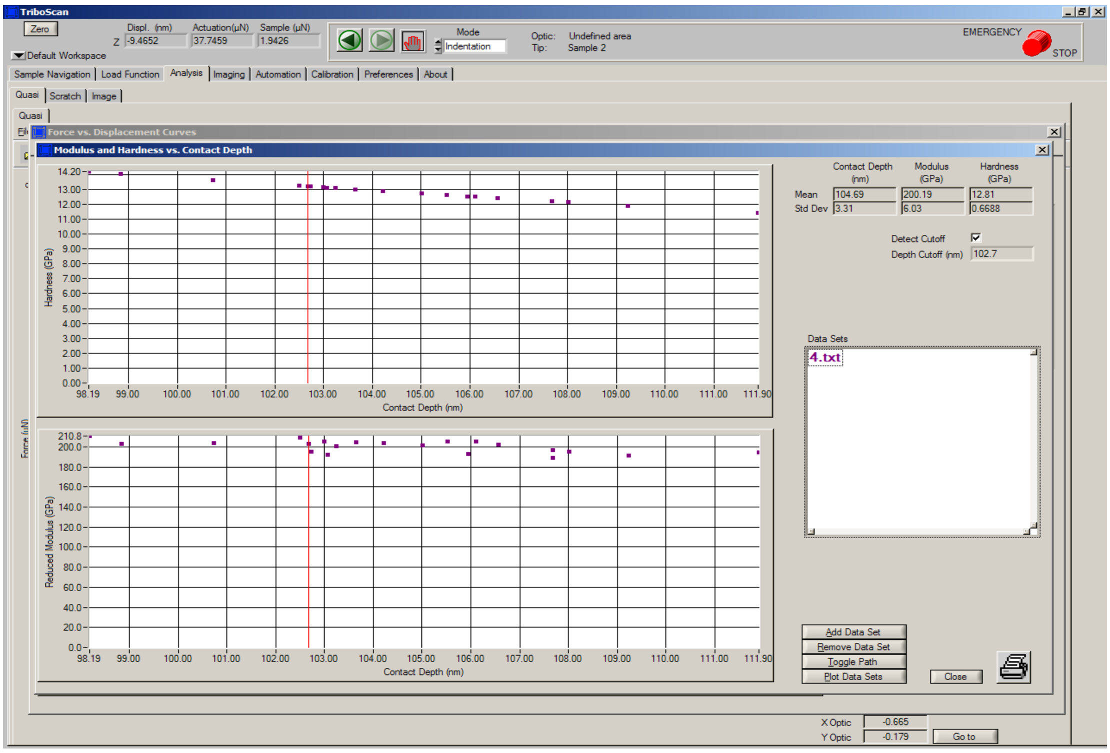

Fig. 4. The nano-hardness and Young's modulus values and their mean values for investigated sample

The dependence of nano-hardness and Young's modulus values on depth under the surface is shown in Fig. 5. It may be noted, that the nano-hardness is highest near the surface. With the increase of the distance from the surface (deep into the material), the nano-hardness of the thin layer decreases, and then stabilizes. The distance between the measuring locations was approximately 5 µm. The thickness of the investigated surface layer was 40 µm.

The mean values of determined nano-hardness and Young's modulus for each element is shown in Tab. 1.

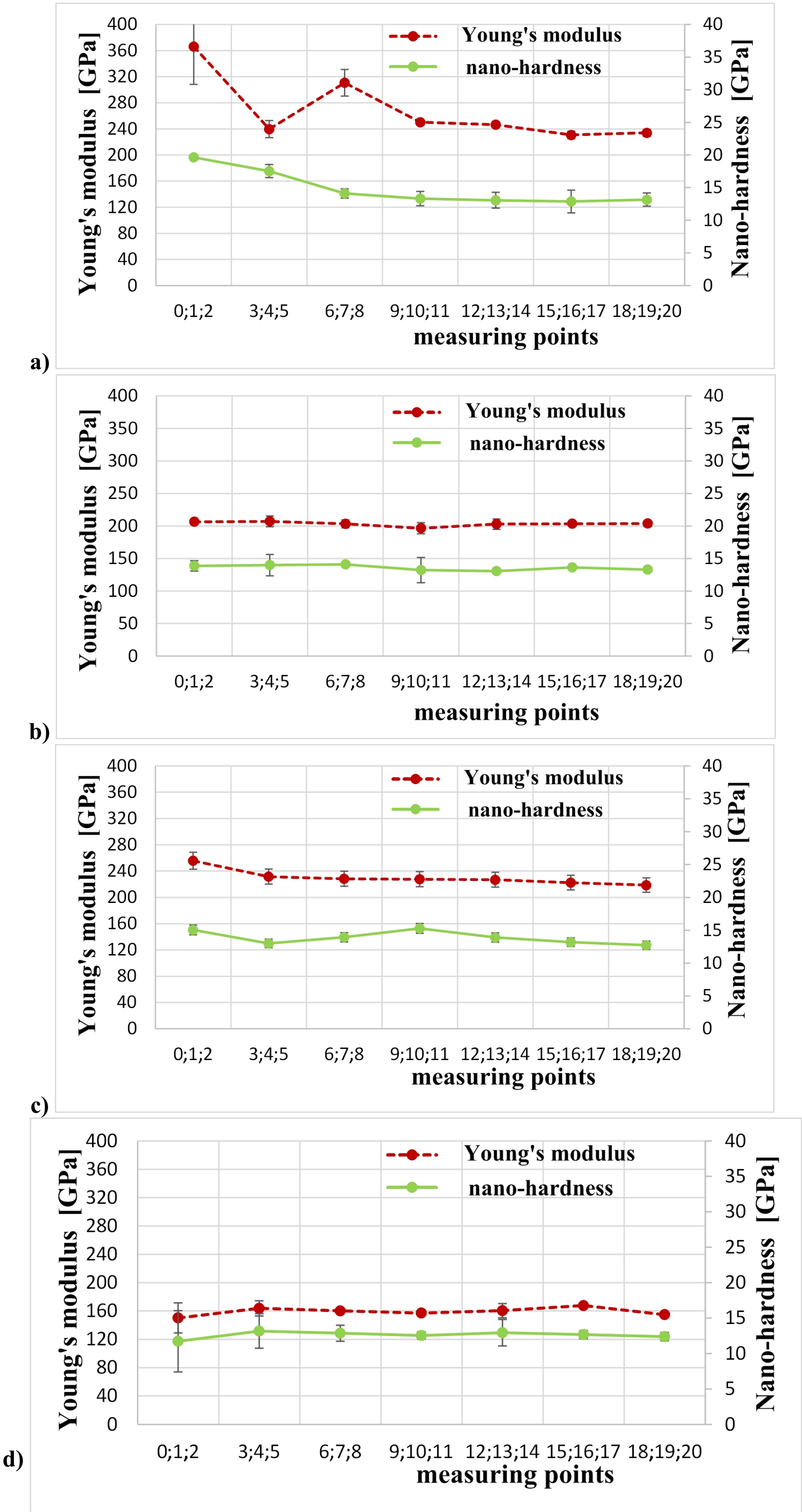

Fig. 5. The dependence of nano-hardness and Young's modulus values on depth under the surface: a) new injector tip body, b) new injector tip needle, c) used injector tip body, d) used injector tip needle

Tab. 1. The values of nano-hardness and Young's modulus of parts of Bosch DLLA 160 S 1305 injector patterns

	Nano-hardness [GPa]	Young's modulus [GPa]
new injector tip body	270.04	14.9
used injector tip body	203.29	13.6
new injector tip needle	230.16	13.9
used injector tip needle	159.84	12.7

4. Conclusions

The results show, that for new injector tip, both for body and needle, there is an increase of nano-hardness with decreasing distance from the surface. Of course, there are some local exceptions from this relation (see Fig. 5a − there was a reduction of nano-hardness of the material as compared to adjacent layers). At a depth of about 30-40 μm the nano-hardness stabilizes and no longer decreases with increasing depth. For the new injector tip body, the difference in nano-hardness between the first layer (depth of about 5 μm) and the last concerned layer (at depth of about 40 μm), is of the order of 30%. The changes in the value of Young's modulus are similar in magnitude.

The nano-hardness and Young's modulus values of used injector tip parts do not change so significantly (about 10%) depending on the depth under surface (see Fig. 5c and 5d).

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