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# THE MECHANICAL PROPERTIES OF PLASMA NITRIDED LAYERS

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## ABSTRACT
*The article deals with mechanical properties of layers which were created by plasma nitriding technology. Nitrided layers apply to steel AISI 4140 were evaluated by metallographic method, GDOES method, microanalysis method and microhardness method. The trend of mechanical properties was experimentally obtained in dependence on length of cavity during plasma nitriding process. Moreover, the influence of nitrogen content on microhardness and Nht thickness of nitrided layer was proved.*
**Keywords:** nitrided layer, plasma nitriding, Nht thickness, cavity

## 1. INTRODUCTION
Plasma nitriding process is special technology when the surface is saturated by nitrogen atoms. During the plasma nitriding process nitrogen diffuses to the bulk of material and creates nitrides of iron and alloy elements [1]. The final microhardness of nitrided layers depends on material and his chemical composition, especially on content of nitride formed elements [2]. Furthermore, microhardness of nitrided layers depends on the nitriding conditions, content of nitrogen and hydrogen in the ambient atmosphere. The ratio of flow gases has remarkable influence on the final nitrided layers. The temperature of ambient atmosphere and the duration of process have significant influence on the Nht thickness of final nitrided layers [3]. Plasma nitriding process is possible to use for surfacing of deep cavities with small diameter. Moreover, the selected ambient pressure enables increase the nitriding in length of cavity. The experiment showed that the increase of pressure changed penetration and behaviour of plasma in the length of cavities.

## 2. EXPERIMENTAL
Bars of 42CrMo4 steel in untreated state were bored to diameters of 6 mm. Specimens of length 400 mm were heat treated in accordance with Tab. 1. Plasma nitriding was carried out in chamber PN 60/60 RÜBIG with following parameters from Tab. 2. Two charges were prepared. First charge was consisted of 1 specimen which was plasma nitrided at the pressure of 5 mbar, next at the pressure of 6 mbar (Tab. 2).

*Table 1. Temperatures of heat-treated steels*

| Procedure | Temperature [°C] |
|---|---|
| Oil quenching | 850 |
| Salt tempering | 300 |

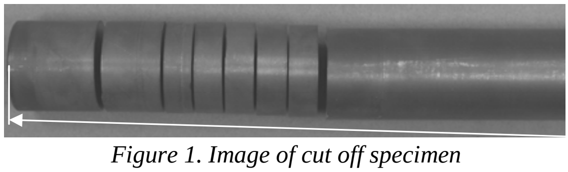


*Figure 1. Image of cut off specimen*

*Table 2. Selected parameters of plasma nitriding process*

| Process | Temperature | Duration | Pressure | | Pulse length | Voltage | Gas flow [l / h] | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Charge 1 | Charge 2 | | | | | |
| | [°C] | [h] | [Pa] | | [µs] | [V] | $H_2$ | $N_2$ | $CH_4$ |
| Sputtering | 480 | 0,5 | 100 | | 50 | 800 | 20 | 2 | 0 |
| Nitriding | 510 | 8 | 500 | 600 | 50 | 510 | 24 | 8 | 0 |

After plasma nitriding process the cavities with diameters of 6 mm and length 600 mm were cut off to small elements (Tab. 3, Fig. 1). All specimens were wet grounded using silicon carbide paper from 120 down to 1000 grit and subsequently polished. Chemical composition of material was measured by GDOES/Bulk method (Tab. 4). Glow discharge optical spectroscopy (GDOES) measurements were performed in LECO SA-2000, with argon glow discharge plasma excitation source, calibration of nitrogen: JK41-1N and NSC4A standards (Tab. 4).

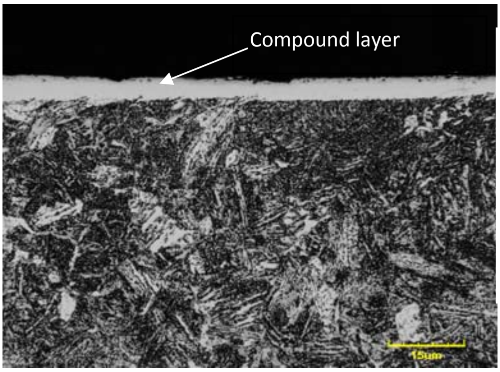
*Table 3. Parameters of plasma nitrided specimens*

| Length [mm] | Pressure 500 Pa | | Pressure 600 Pa | |
|---|---|---|---|---|
| | Nht thickness of nitrided layer [mm] | N [%wt] | Nht thickness of nitrided layer [mm] | N [%wt] |
| 30 | 0,33 | 5,69 | 0,23 | 5,71 |
| 52 | 0,30 | 5,09 | 0,22 | 5,19 |
| 64 | 0,34 | 6,55 | 0,27 | 5,81 |
| 76 | 0,33 | 5,71 | 0,20 | 5,42 |
| 88 | 0,32 | 5,72 | 0,23 | 5,76 |
| 100 | 0,32 | 5,71 | 0,23 | 5,77 |
| 112 | 0,34 | 6,26 | 0,17 | 4,93 |
| 124 | 0,31 | 5,64 | 0,18 | 5,04 |
| 136 | 0,31 | 6,15 | 0,23 | 5,63 |
| 148 | 0,18 | 4,26 | 0,21 | 5,53 |
| 160 | 0,10 | 0,95 | 0,22 | 5,65 |
| 172 | 0,00 | 1,11 | 0,20 | 5,38 |
| 184 | 0,00 | 1,00 | 0,24 | 5,76 |
| 196 | 0,00 | 1,21 | 0,00 | 3,28 |

*Table 4. Chemical composition of steel AISI 4140*

| **Chemical composition (%)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **C** | **Mn** | **Si** | **Cr** | **Ni** | **Mo** | **Cu** | **P** | **S** |
| GDOS/Bulk | 0,40 | 0,64 | 0,28 | 1,14 | 0,32 | 0,16 | | < 0,012 | < 0,012 |
| DIN standard | 0,38 0,40 | 0,50 0,80 | 0,17 0,37 | 0,90 1,20 | < 0,50 | 0,15 0,30 | < 0,30 | < 0,030 | < 0,030 |
| Parameters of GDOES/Bulk analysis: U= 800 V, I = 30 mA, $p_{Ar}$ = 314 Pa | | | | | | | | | |

Confocal laser microscope LEXT OLS 3000 with outstanding resolution of 0.12 µm and magnification range from 120x to 12400x were used for evaluation of structure (Fig. 2).



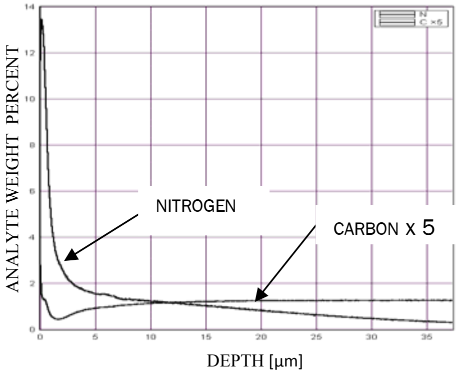
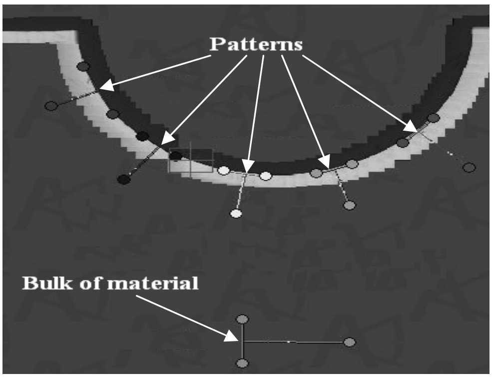




*Figure 2. The chemical etched (NITAL) confocal cross-sectional structure in length 170 mm*

*Figure 3. Concentration profiles obtained by GDOES method*

Microhardness measurements were measured by Vickers microhadness method on automatic microhardness tester LM 247 AT LECO at 50 g load and 10 s dwell time. The major Vickers microhardness numbers were derived from five measurements. The system of measurement is demonstrated in Fig. 4 and one of measurements is showed in Fig. 4a.



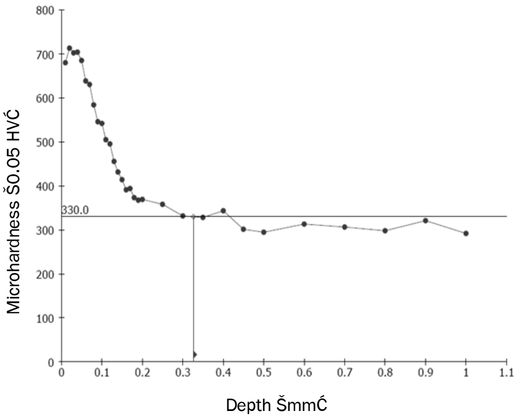




*Figure 4. Image of measured specimen*

*Figure 4a. Microhardness depth profile of a plasma nitrided layer*

The local chemical compositions of plasma nitrided layers in length were observed by electron microscope method in combination with energy dispersive micro analyser PHILIPS EDAX. Measurement of nitrogen content was performed from two local spaces by 25x magnification. The results from analysis are shown in table 3.

## 3. RESULT AND DISCUSSION

Nht thickness of plasma nitrided layer was measured in accordance with DIN 50190 standard. Plasma nitriding process increased the value of microhardness of about 350 HV. The maximum Nht thickness 0.33 µm was obtained at pressure of 500 Pa in length 30 mm. This Nht thickness decreased irregularly with increase length (Fig. 5, 6). In length 172 mm no nitrided layer was measured (Tab. 3). The content of nitrogen was conformed to Nht thickness (Fig. 6). At pressure of 600 Pa the values of Nht thickness were lower than in previous case. In despite of lower Nht value the nitriding in length were lengthened of 24 mm.

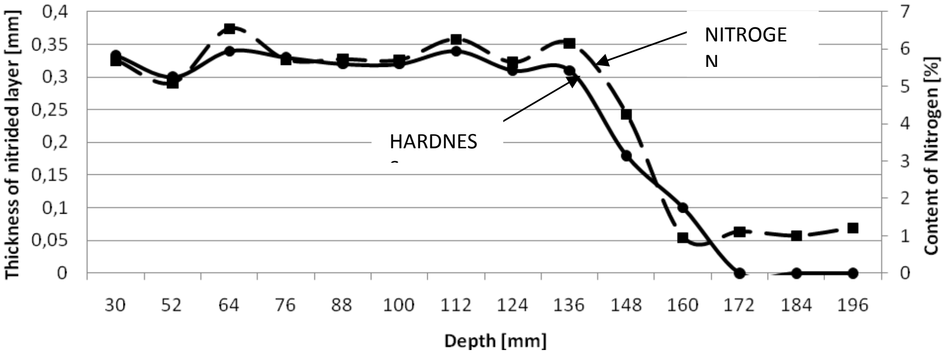


*Figure 5. The limited thickness in dependence on the content of nitrogen by pressure 500 Pa*

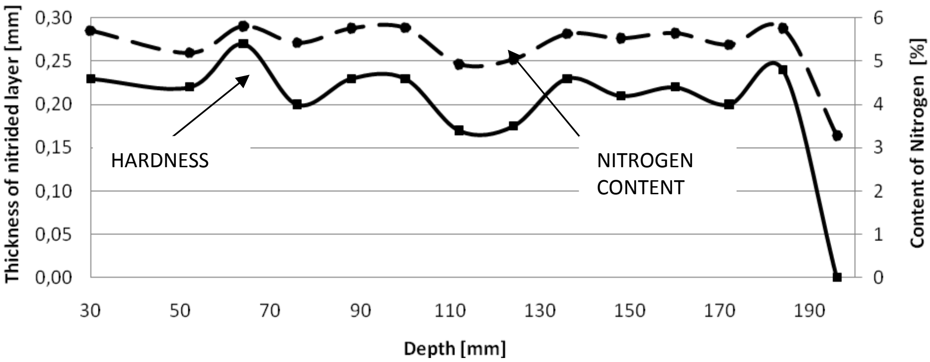


*Figure 6. The limited thickness in dependence on the content of nitrogen by pressure 600 Pa*

## 4. SUMMARY

The cavities with the diameter of 6 mm were investigated and subsequently compared. During experiments the utilization of plasma nitriding process for nitriding cavities with small diameters of 6 mm was proved. The increasing of pressure from 500 Pa to 600 Pa lengthened plasma nitriding in length of cavity which is given in Tab. 3. Moreover, the influence between nitrogen content and the Nht thickness or microhardness were found (Fig. 4, 5). The mechanical and corrosion properties were improved.

## ACKNOWLEDGEMENT

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