

# Effects of Plasma Nitriding Temperature on the Properties of 1.3207 Type High Speed Steel

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## Abstract

Active screen plasma nitriding on HS 10-4-3-10 high-speed steel specimens was performed at three different low nitriding temperatures while trying to keep the other nitriding parameters uniform. In addition, two extra samples were made to increase the treatment time. Optical microscopic investigation and microhardness testing were performed on the segments of the samples, and their qualitative composition was determined by energy-dispersive X-ray spectrometry. Based on the measurements, it is stated that the hardness of the surface can be increased 50% with active screen plasma nitriding.

**Keywords:** *active screen, plasma nitriding, high-speed steel.*

## 1. Introduction

In the 21st century, the requirements for steel are becoming stricter, and the expectations more complex. Different mechanical properties are often required on the surface and cross-section of the material. In this case, creating a heterogeneous microstructure in a cross-section can be a solution. There are two options for this: changing the microstructure of the surface, or modifying the chemical composition in the surface layer. The latter group of solutions includes the thermochemical process we chose, nitriding. [1, 2]

In this thermochemical surface treatment through adsorption and diffusion, nitrogen is delivered to the material's surface, where it creates metalloid phases and a high hardness and wear-resistant layer. The quality of nitriding is influenced by the carbon and other alloy content of the steel in addition to the process parameters. The effect of alloying elements is based primarily on their affinity for nitrogen, similar to iron. Based on the free energy required for the formation of different nitrides, the stability of each alloy can be deduced, and in this way, can be distinguished as strong, medium, and weak ni-

tride formers. Alloys have two significant effects during nitriding: it reacts with nitrogen through diffusion, forming hard nitrides and increasing the surface hardness, and it decelerates the diffusion of nitrogen, thus reducing the depth of the formed layer. From an industrial perspective, the hardest surface is not desirable, but the goal is to create a deep, mechanically resistant layer using the most economical production method [3].

In previous research, high-speed steels were already treated with a traditional, direct current plasma nitriding process [4, 5]. Akbari et al. [6] determined that after 8 hours of nitriding, a 140 μm diffusion zone was created without a compound layer containing scattered Fe<sub>3</sub>N and Fe<sub>4</sub>N precipitates. During our research, we carried out active screen plasma nitriding at different temperatures on the 1.3207 high-speed steel material quality in order to discover whether these properties of high-speed steel with excellent hardness and wear resistance can be increased, given the typically high alloy content of high-speed steels.

## 2. Experimental methodology

The next chapter will describe the chosen material, technology, and methods.

## 2.1. Material

The chosen steel has outstanding hardness and wear resistance among commercially available high-speed steels yet poor machinability. From the point of steel using view, it is an excellent turning and milling tool for roughing and finishing work, woodworking tools, heavy-duty cold working tools and tool inserts.

The alloys of the selected material are nitride formers, and their quantity is also high in the steel, so because of the treatment, an outstanding surface hardness and thin layer thickness will be expected at the same time [7].

The material quality used for the research nominally includes the following alloys based on the ISO 4957 standard: 1.2–1.35% C,  $\leq 0.4\%$  Mn,  $\leq 0.45\%$  Si,  $\leq 0.03\%$  S, 3.8–4.5% Cr, 3.2–3.9% Mo, 3.0–3.5% V, 9.0–10.0% W, 9.5–10.5% Co, and Fe.

The samples were used for the treatment, also known as 1.3207 (HS10–4–3–10) steel. It was acquired in the form of a 12×3×160 mm rod. This steel is also commercially available under the name HSS CO10.

## 2.2. Active screen plasma nitriding

The active screen was used during the surface treatment process, which was made from unalloyed steel with a diameter of 100 mm and a hole diameter of 8 mm.

The effect of the material of the screen and its distance from the sample was neglected, considering that all 5 test specimens were affected uniformly by these parameters.

The voltage and the pressure of the 75% N<sub>2</sub> - 25% H<sub>2</sub> gas mixture were kept at the same value. Since the primary goal is to maintain the temperature set for the sample, it was sometimes necessary to slightly deviate from the uniform pressure or voltage during the entire treatment time. The treatment parameters and produced samples are listed in Table 1:

**Table 1.** Nitriding parameters of the samples produced for the examinations

No.	Temperature (°C)	Time (h)
1	360	5
2	440	5
3	520	5
4	360	8
5	520	8

## 2.3. Methods

The sample cross-sections were prepared by grinding on SiC paper after the surface treatment, followed by polishing with 3 and 1 μm diamond suspension. The completed samples were etched with a Beraha II-type etchant [8].

The formed surface layer was examined with a scanning electron microscope (type: Zeiss Evo Ma 10), and the surface nitrogen content of the samples was measured with an energy dispersive X-ray spectrometer, thus proving the success of the surface treatments, establishing the effectiveness of the different treatment temperatures.

Finally, microhardness tests were carried out with a load of 200 grams to record the hardness profile and the surface hardness of the samples, for which a Buehler 1100 type microhardness tester was used.

## 3. Results and discussion

Based on the scanning electron microscope examinations, no compound layer was formed on the surface of the high-speed steel samples during the entire treatment in the temperature range and treatment times, which can also be observed in Figures 1. and 2. The surface composition analysis made with an energy dispersive X-ray spectrometer reliably measured the nitrogen content of all samples (Table 2). The measurement was carried out along the cross-sectional, on the part marked with yellow in Figure 2.

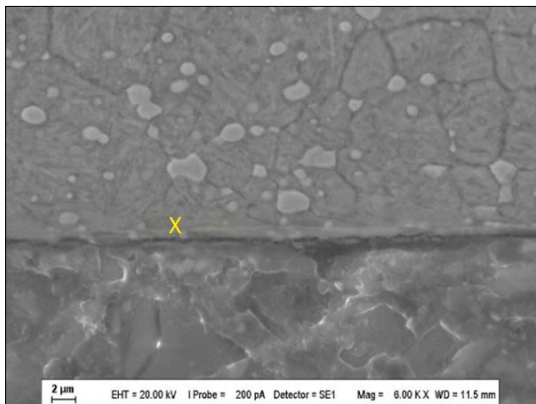
It can be concluded that a compound layer was not formed on the samples, but a diffusion layer was formed. The nitrogen content was increased with increasing treatment temperature or treatment time.

This phenomenon can be attributed to faster diffusion at higher temperatures or to the time available for the phenomenon to occur [9].

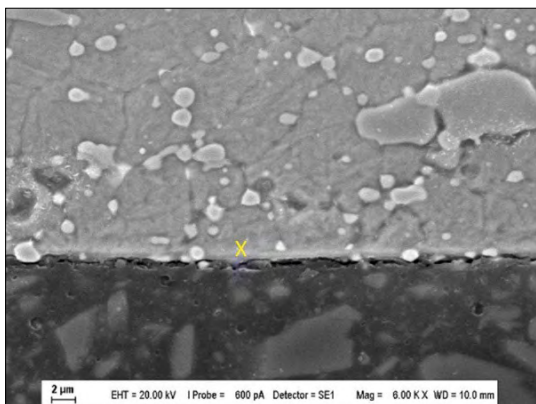
The result of the hardness measurement can be seen in Figure 3.

**Table 2.** Measurement data on the cross-sectional in the subsurface (weight ratio, %)

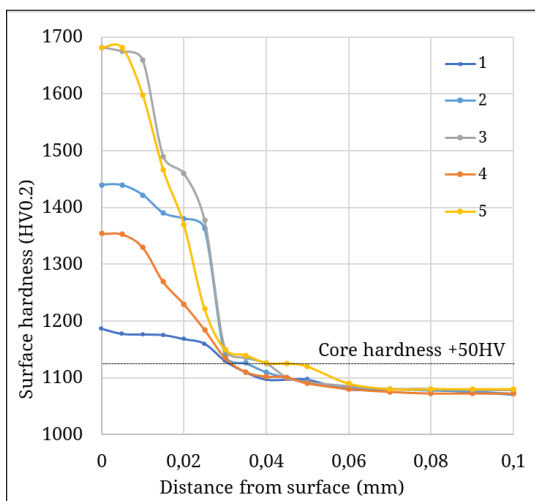
No.	N	V	Mo	W	Co
1	3.03	1.25	1.93	5.15	9.57
2	4.56	1.09	2.3	4.21	9.91
3	6.18	5.75	4.35	11.7	9.79
4	6.99	2.73	3.90	8.56	8.55
5	13.0	2.46	4.33	9.45	9.52



**Figure 1.** Cross-section of the sample treated at 520 °C for 5 hours (yellow cross marks the measurement spots).



**Figure 2.** Section of the sample treated at 520 °C for 8 hours (yellow cross marks the measurement spots)



**Figure 3.** Hardness profile of samples.

**Table 3.** The layer thickness of the diffusion zone

No.	Layer thickness (μm)
1	31
2	36
3	40
4	33
5	45

It can be clearly seen that the maximum hardness was increased with increasing temperature. Based on the ISO 18203:2016 standard, the developed diffusion layer thicknesses were determined using the curves. The value of the surface layer thickness was equal to the point where the core hardness + 50HV was reached. [10]. Table 3 contains the determined values.

#### 4. Conclusions

With the technology of active screen plasma nitriding of high-speed steels, the surface hardness can be increased even at low temperatures, while at higher applied temperatures, the hardness value increases significantly. By increasing the time, the surface hardness can be effectively increased at lower temperatures but not at higher temperatures.

The layer thickness of the diffusion zone can be increased minimally during the nitriding of high-speed steels by increasing the temperature, but no compound layer was formed. By increasing the treatment time, the thickness of the formed diffusion layer can be increased more significantly.

It is concluded that a compound layer cannot be formed by active screen plasma nitriding during a processing time of 5–8 hours, while the diffusion zone was created even at the lowest test temperature.

#### Acknowledgement

This work was supported by the National Research, Development and Innovation Office (NKFIH), under grant agreement OTKA PD\_22 142307.

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