# THERMAL AND THERMOCHEMICAL TREATMENT OF STEEL 4Cr12Ni8Mn8MoVNb

## ТЕРМИЧЕСКАЯ И ХИМИКО-ТЕРМИЧЕСКАЯ ОБРАБОТКА СТАЛИ 4Х12Н8Г8МФБ

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## Abstract

*The effects of thermal treatment and subsequent nitriding in low-temperature plasma on the phase constitution, surface microhardness and thickness of the nitrided layer of high-temperature carbide-hardened austenitic steel 4Cr12Ni8Mn8MoVNb have been investigated.*

*Thermally pre-treated specimens have been subject to ion nitriding at a temperature within 540 ÷ 620 °C, ammonia pressure within 150 ÷300 Pa and treatment duration of 2 to 8 h.*

*It has been found that upon quench hardening and twofold tempering the steel hardness becomes 38 HRC for 2 or 3 of the grain-size number, and after nitriding its hardness attains 1100* $HV_{0.2}$*, while a magnetic phase of the surface from 1 to 5 % is recorded.*

## *1. Introduction*

High-temperature austenitic steels are used in manufacturing engine valves, gas turbine blades, wheel tyres and other parts operating at temperatures within 600 ÷ 700 °C. Under conditions of lower level of loading the working temperature may attain up to 1000 °C [1, 2]. High-temperature austenitic steels contain mainly 0.06 to 0.5 percent of carbon and a large quantity of chromium (10 to 26 %). To achieve a stable austenitic structure, nickel (8 ÷ 35 %) or manganese are additionally introduced.

Austenitic steels may be divided into two groups [2, 3]:

- steels not suitable for hardening by thermal treatment, i. e. those, which are not susceptible to dispersion hardening (Cr18Ni10T, Cr25Ni10Si2);
- steels suitable for hardening by thermal treatment (4Cr12Ni8Mn8MoVNb, 0Cr14Ni28W3T3AlB).

Hardening of this type is based on the precipitation of carbides, carbonitrides or intermetallic phases. A characteristic feature of carbide-hardened austenitic steels (4Cr12Ni8Mn8MoVNb) is the precipitation of a considerable quantity of carbides during the process of tempering (ageing). These carbide phases provide a high degree of strength at increased temperatures with preserving sufficiently high ductility [3]. The thermal treatment of this group of austenitic steels consists in quench hardening (1100 ÷ 1200 °C) and subsequent single or twofold tempering up to temperatures that are a little bit higher than the working one or equal to it [2].

In austenitic steels no $\gamma \leftrightarrow \alpha$ transformation occurs, so they can be subject to nitriding at temperatures higher than 570 °C [4]. It is recommended that the carbide-hardened austenitic steels be nitrided at the temperatures of their precipitation hardening [5, 6].

As the steel 4Cr12Ni8Mn8MoVNb (4Х12Н8Г8МФБ - GOST 5632-72) hardens strongly, there should not be any interruption between first and second tempering, otherwise cracks might occur. To avoid crack formation it is recommended to perform the twofold tempering in the same furnace. Under these conditions of thermal treatment, however, the realization of nitriding at the temperature of precipitation hardening will be difficult, and it will not be possible at all to combine ion nitriding with the process of tempering.

The purpose of the present work is to investigate the effect of thermal treatment as well as that of technological factors of nitriding upon the phase constitution, surface microhardness and thickness of the nitrided layer of a high-temperature carbide-hardened austenitic steel, namely 4Cr12Ni8Mn8MoVNb.

## *2. Methodology of the investigation*

The chemical composition of the steel studied has been analyzed by means of a device for automatic analysis “Spectrotest” and the result is shown in Table 1. Specimens (20 x 20 x 10 mm) have been made of said steel and thermally treated according to a regime specified in Table 2 [7].

Heating of specimens for quench hardening and tempering has been performed in a box-furnace filled with oxidizing medium. In such a way the thermally treated specimens are subject to ion nitriding in the ION-20 installation at temperature of nitriding (tn) within 540 to 620 °C, ammonia pressure in the chamber (P) within 150 to 300 Pa, and treatment duration ($\tau$) of 2 to 8 h.

Microscopes “Neophot - 2” and “MMR - 4” have been used in metallographic examinations. Measuring the microhardness has been performed by means of microhardness tester “SHIMADZU” for a load of 1.96 N. The magnetic properties of nitrided specimens have been determined by using a “Ferritgehaltmesser-1.053” device. The radiographic structural analysis has been performed on an x-ray diffraction meter “DRON-1” in cobalt radiation.

## *3. Results and discussion*

### *3.1. Thermally treated specimens*

The hardness of quench-hardened and twofold tempered steel is shown in Table 3.

In order to provide better solubility of alloying elements, the quench hardening of the steel has been performed from a sufficiently high temperature value, namely 1170 °C, at which, however, the austenitic grains grow up, their average size attaining 0.125 ÷ 0.177 mm (2 to 3 grain-size number), Fig. 1. This leads to an increase in the high-temperature strength and creep resistance, but diminishes the steel toughness [2, 3]. From Table 3 it can be seen that after quench hardening and twofold tempering at 650° C and 780° C the hardness increases with more than 70 percent.

**Table 1.** Chemical composition of steel 4Cr12Ni8Mn8MoVNb

| Chemical elements, % | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C | Cr | Ni | Mn | Si | P | Cu | Mo | V | W | Co | Ti | Nb |
| 0.37 | 13.2 | 6.23 | 7.86 | 0.42 | 0.02 | 0.15 | 0.7 | 1.69 | 0.05 | 0.1 | 0.02 | 0.32 |

**Table 2.** Regimes of thermal treatment of the steel

| Quench hardening | | | Tempering | | |
|---|---|---|---|---|---|
| t, °C | τ, h | Cooling medium | t, °C | τ, h | Cooling medium |
| 1170 | 2.5 | Water | 650 | 16 | Air |
| | | | 780 | 16 | Air |

**Table 3.** Hardness of the steel in initial and thermally treated states

| Steel | Hardness, HRC | | | |
|---|---|---|---|---|
| | *In initial state* | *After quench hardening* | *After tempering* | |
| | | | 650 °C | 780 °C |
| 4Cr12Ni8Mn8MoVNb | 24 | 20 | 33 | 38 |

**Table 4.** Regimes of nitriding and results of the investigation of nitrided layers

| No. of regime | Temperature of nitriding, $t_n$ °C | Pressure of $NH_3$ Pa | Time of nitriding, τ h | Hardness of layer, $HV_{0,2}$ MPa | Thickness of layer, $\delta_{total}$ μm | Magnetic phase % | Quantity of γ'–phase in layer, % | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | 4 μm | 8 μm |
| 1 | 540 | 150 | 5 | 10950 | 65 | 3.3 | 45 | 35 |
| 2 | 540 | 150 | 8 | 10720 | 100 | 4.2 | 75 | 70 |
| 3 | 580 | 300 | 5 | 10610 | 90 | 2.8 | 78 | 66 |
| 4 | 580 | 300 | 8 | 10720 | 105 | 2.9 | 80 | 75 |
| 5 | 620 | 300 | 2 | 11070 | 70 | 1.5 | 55 | 40 |

The increase in hardness is associated not only with the enlarged interphase boundary, but also with the presence of fine-dispersion carbide particles, precipitated predominantly along the austenite boundary, Fig. 1. After second tempering (at 780° C) the steel hardness has been increased to 38 HRC. This is explained by the continuation of the process of the carbide phases precipitation and their impossibility to coagulate at these temperatures and duration of tempering.

### *3.2. Ion-nitrided specimens*

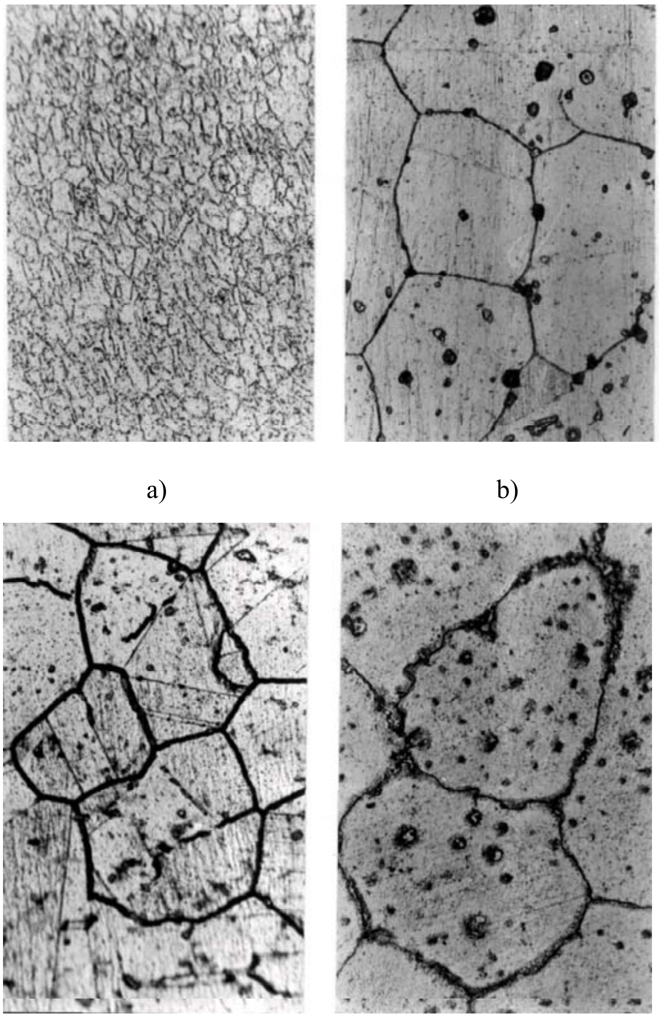
The impact of diverse conditions of nitriding upon the surface hardness and thickness of the layer can be seen from Table 4.

The layer obtained after ion nitriding can be seen clearly on the surface of the austenitic steel, Fig. 2. When nitriding an oxidized surface the nitrogen is diffused through the oxidized layer and the latter is outlined against the nitrided one, Fig. 2a. Results given in Table 4 indicate that the layer thickness becomes greater with the increase in temperature of nitriding and with the prolongation of treatment time (Fig. 2), the microhardness not being substantially modified. For the austenitic steel investigated it is obvious that the higher temperatures of nitriding, too, cannot bring along coagulation of nitride particles, and as a result the hardness remains the same. The microhardness in the layer's depth is nearly constant, being changed stepwise during the transition to main material, Fig. 3.

Depending on the treatment regime, the nitrided layer obtained is of first or second class of brittleness, which is determined by the appearance of the diamond pyramid imprint in accordance with VIAM brittleness scale [5]. For regimes 3, 4 and 5 (Table 4) the layer is not brittle (class of brittleness 1), and for regimes 1 and 2 it is lightly brittle (class 2); parts with any of the two classes of brittleness being admissible of operational application. The increased brittleness of the layer (class 2) results from the low temperature of nitriding and the steel coarse-grained structure.

Twins and slipping lines (Fig. 2d), which are intersection lines of the sliding planes with the external surfaces of crystals, are well visible in the surface layer [8]. Its formation results from the occurrence of plastic deformation in the surface when the specimens are ground. The presence of slipping lines affects favorably the diffusion of nitrogen into the volume of the grain [5].

On the basis of the metallographic and x-ray structural analyses performed (Table 4) it has been found out that no dense connected zone was obtained in the nitrided layer of any of the specimens, Fig. 2b. The obtained connected zone is of the γ'-phase type ($Fe_4N$).



a) b)

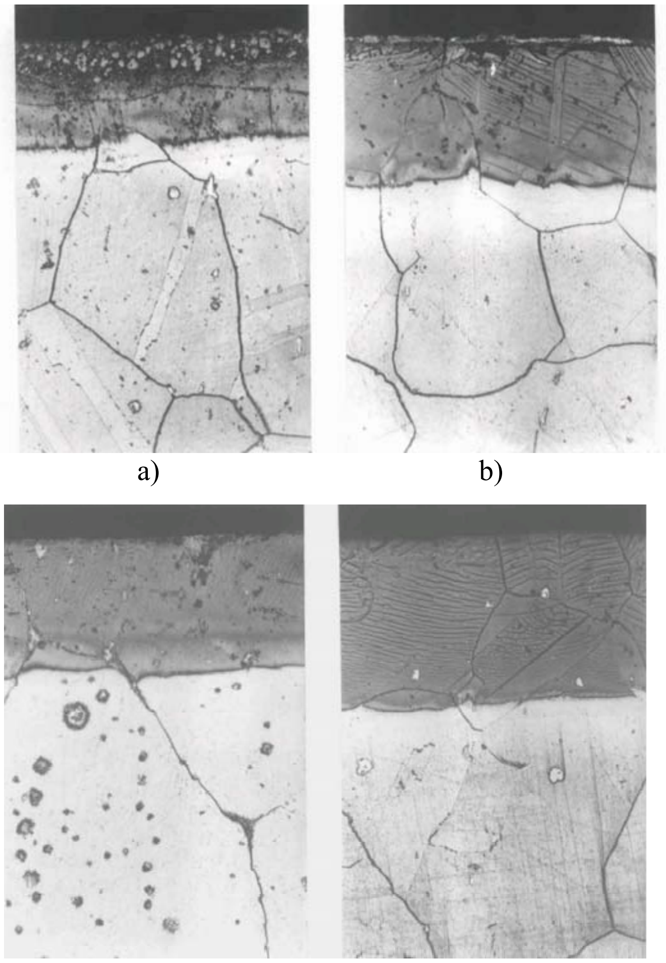
c) d)

**Fig. 1** Microstructures of steel 4Cr12Ni8Mn8MoVNb (x500) ***a)*** *in initial state;* ***b)*** *after quench hardening;* ***c)*** *after quench hardening and single tempering;* ***d)*** *after quench hardening and twofold tempering.*

The largest quantity of γ'-phase (80 %) has been obtained for the fourth regime of nitriding. Of the three technological factors ($t_n$, P, τ) most substantial influence on γ'-phase formation in steel 4Cr12Ni8Mn8MoVNb is exerted by the temperature of nitriding. Due to the higher diffusion rates at higher temperatures the γ-solid solution is being saturated with nitrogen for a shorter period. It is obvious that the pressure of ammonia (150 ÷ 300 Pa) in the chamber does not play an active part in providing of a greater quantity of nitrogen on the surface for these periods (5 to 8 h) of treating the austenitic structure.

*3.3. Magnetic properties of the surface after nitriding*

It can be seen in Table 4 that after ion nitriding of the austenitic steel investigated the magnetic properties of the surface are modified by about 1 to 5 percent. The results show that at higher temperatures of nitriding there is a smaller quantity of magnetic phase, irrespective of the greater layer thickness. This is probably due to lower concentration of nitrogen in the surface of the layer.



a) b)

c) d)

**Fig. 2** Microstructures of ion-nitrided steel 4Cr12Ni8Mn8MoVNb (x500)

***a)*** *$t_n$ = 540 °C, P = 150 Pa, τ = 5 h;*

***b)*** *$t_n$ = 540 °C, P = 150 Pa, τ = 8 h;*

***c)*** *$t_n$ = 580 °C, P = 300 Pa, τ = 5 ;*

***d)*** *$t_n$ = 580 °C, P = 300 Pa, τ = 8 h.*

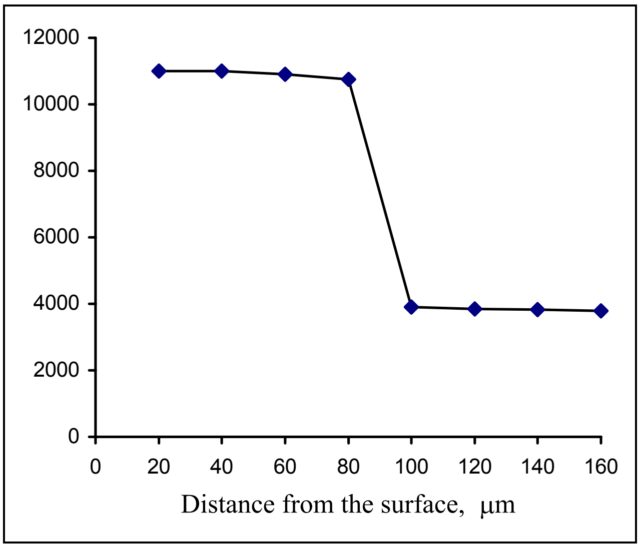


**Fig. 3** Microhardness distribution in the depth of the nitrided layer of steel 4Cr12Ni8Mn8MoVNb: $t_n = 540°C, P = 150Pa,\ \tau = 8h.$

## *4. CONCLUSIONS*

- It is found that after quench hardening and twofold tempering the steel hardness attains 38 HRC for grain-size number 2 or 3.
- It is demonstrated that the steel 4Cr12Ni8Mn8MoVNb is well suited for nitriding. The layer obtained is characterized by high hardness ($HV_{0,2} = 11000$ MPa) and low brittleness.
- It is found that after nitriding of the austenitic steel the magnetic properties of the surface are modified by 1 to 5 percent depending on the treatment regime.
- It is demonstrated that for ion nitriding of steel 4Cr12Ni8Mn8MoVNb no dense connected γ'-zone is obtained.

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