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## CARBONITRIDING AUSTENITE STEEL IN GLOW DISCHARGE PLASMA

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**ABSTRACT:** The aim of the present paper is to study the influence of the process of carbonitriding in low-temperature plasma in an actuating medium of ammonia and gas corgon (82% Ar and 18% CO<sub>2</sub>) on the surface micro-hardness and total thickness of the carbonitrided layer in 37Cr12Mn8Ni8MoVNb austenitic steel. The obtained results show that at the higher pressure (P = 700Pa) of both gases – corgon and ammonia – layers with higher micro-hardness (1200HV<sub>0.1</sub>) are formed and the thickness of their combined zone is 2 μm. It has also been established that during the process of ion nitriding layers without a combined zone are formed, while in carbonitriding the combined zone reaches up to 2 μm.

**Keywords:** carbonitriding, austenitic steel, layers

### 1. INTRODUCTION

Nitriding and carbonitriding are basic processes for surface hardening of details and tools made of iron-carbon alloys, during which either nitrogen only or both carbon and nitrogen are simultaneously introduced into the surface layer.

In case of conducting these two processes in conventional gas furnaces or salt baths, it is impossible to regulate in a reliable way the thickness and the composition of the obtained layers, what necessitates varying with the potentials of carbon and nitrogen in the gas mixture or in the liquid medium. The percentage of nitrogen and active carbon is defined by a small number of parameters – temperature and composition of the gas medium - and the possibilities for variation are limited. In the processes of carbonitriding and nitriding in glow-discharge plasma these difficulties are resolved, and this is the major advantage of the method. The use of glow electric discharge for treating details is a perspective method of material nitriding and carbonitriding in modern machine building.

Works [1,2,3,5] consider mainly the mechanism of building, the structure and the properties of the nitrided layers, obtained in low-temperature plasma, while [3,4,6] discuss basic problems related to carbonitriding in conventional gas furnaces and [7,9,10,11,12,13] speculate on carbonitriding in glow electric discharge. There is lack of data about carbonitriding in glow-discharge plasma in an actuating medium, consisting of ammonia and corgon (82% Ar and 18% CO<sub>2</sub>), and the available information of comparative investigations between the two processes – nitriding and carbonitriding – is also insufficient.

It has been established in works [4,7,8] that, when in the process of carbonitriding propane-butane is used as a carbon-carrier, the phase composition of the combined zone in the carbonitrided layer could not be precisely regulated. Better results are obtained in result of using a mixture of methane and argon [7]. In metal welding the role of the protective gas is often taken by corgon, which contains both argon and carbon dioxide in a particular ratio.

The objective of the present paper is to investigate the possibility to use corgon not only in welding but also as an indirect carbon-carrier in the process of simultaneous saturation of the metal surface with nitrogen and carbon (carbonitriding) at low temperatures. The small percentage of (18%) carbon dioxide in the gas corgon makes it possible to regulate the amount of carbon, introduced into the vacuum chamber. There is no data in the considered literature about nitriding and

carbonitriding in glow-discharge plasma in an actuating medium consisting of ammonia and corgon (82% Ar and 18% CO<sub>2</sub>). The 37Cr12Mn8Ni8MoVNb steel is with austenitic structure and it is used for producing turbinedisc, valves forengines, wheels with bandage, and other details work in gat up to 800°C. In order to achieve a stable austenitic structure, nickel and manganese are introduced additionally.

The aim of the present work is to investigate the influence of nitriding and carbonitriding in low temperature plasma, in an actuating medium, consisting of ammonia and gas corgon (82% Ar and 18% CO<sub>2</sub>), upon the surface hardness and the total thickness of the nitrided and carbonitrided layers of the austenitic steel 37Cr12Mn8Ni8MoVNb.

**2. INVESTIGATED MATERIALS AND MODES OF TREATMENT**

Austenitic steel 37Cr12Mn8Ni8MoVNb (GOST) is subjected to investigation. Its chemical composition is checked by the equipment for automatic analysis Spectrotest and given in Table 1.

**Table 1.** Chemical composition of the steel

Type	Chemical elements, percentage									
	C	Si	Mn	Cr	Ni	S	P	Nb	V	Mo
37Cr12Mn8Ni8MoVNb	0,37	0,3	7,7	13,2	6,2	0,02	0,025	0,03	1.69	0.7

The requirement for a preliminary treatment is imposed mainly by the following consideration: for achieving the desired mechanical parameters and structure, enabling uniform distribution of nitrogen and carbon in depth and favorable course of diffusion.

Test samples are made of 37Cr12Mn8Ni8MoVNb steel with dimensions 15X15X10mm, and they are treated thermally in a chamber furnace in an oxidizing medium under modes, given in Table 2. The samples from the investigated steel are nitrided and carbonitrided in the installation “Ion – 20” according to the modes, given in Table 3. Ammonia (NH<sub>3</sub>) and corgon are used as saturating gases in different percentage ratio. The temperature of treatment is 550°C.

**Table 2.** Modes of preliminary treatment

Steel	Quenching t <sub>quen</sub> , °C	Cooling medium	Tempering t <sub>temp</sub> , °C	Cooling medium
37Cr12Mn8Ni8MoVNb	1170	water	650	air
			780	air

**Table 3.** Modes of nitriding and carbonitriding

No of the mode	Treatment	t [h]	P <sub>1 NH3</sub> [Pa]	P <sub>2 corgon</sub> [Pa]	P <sub>total</sub> [Pa]
1	carbonitriding	2	350	350	700
2	carbonitriding	6	350	350	700
3	carbonitriding	2	360	40	400
4	carbonitriding	6	360	40	400
5	carbonitriding	2	280	120	400
6	nitriding	4	400	-	400

**3. METHODOLOGY OF INVESTIGATION**

In order to clear out the morphological peculiarities of the nitrided and carbonitrided layers, metallographic analysis has been performed.

When defining the structure and the thickness of the obtained nitrided layers a microscope – Axioscop – has been used and metallographic pictures taken.

The thickness of the nitrided layer has been defined by the depth, at which hardness, equal to the core plus 50, has been achieved.

Measuring the micro-hardness of the nitrided samples has been accomplished by means of a micro hardness-meter "Shimadzu" at a load of 0.98 N, following the Vickers' method.

**4. EXPERIMENTAL RESULTS AND ANALYSIS**

**4.1. Preliminary thermal treatment**

The results from measuring the hardness after the thermal treatment are given in Table 4. During the process of quenching the 37Cr12Mn8Ni8MoVNb steel, homogeneous alloyed austenitic structure with low hardness – 21 HRC – has been fixed. During the subsequent double ageing the steel hardens (first ageing – 33 HRC, second ageing – 39 HRC, Table 4) as a result of the separation of disperse carbides in the grain boundary of the supersaturated austenitic structure.

**Table 4.** Results from the preliminary thermal treatment

Steel	Hardness, HRC	
	Quenching	Tempering
37Cr12Mn8Ni8MoVNb	21	33(650 °C) 39(780°C)

#### 4.2. Ion carbonitriding

The maximum thickness –  $HV_{0.1}$  – and the total thickness –  $\delta_{tot}$  – of the nitrided and carbonitrided layers have been defined by means of measuring the micro-hardness of the thermally treated and ion nitrided and carbonitrided samples in-depth, while the thickness of the combined zone ( $\delta_{c.z.}$ ) of both layers has been defined with the help of a metallographic microscope.

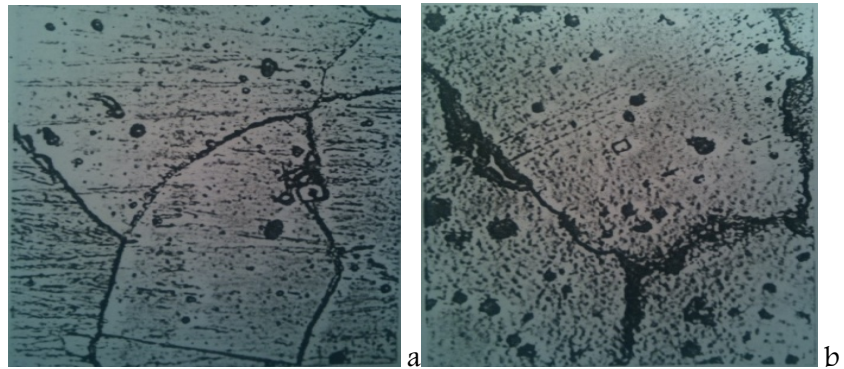
The obtained results are given in Table 5. After ion carbonitriding the obtained layer is easily seen on the surface of the austenitic steel – Figure 2. In the process of nitriding 37Cr12Mn8Ni8MoVNb steel under the mode 6 from Table 5 (temperature 550 °C, ammonia pressure 400Pa, time 4h), a layer with 55 $\mu$ m thickness and 1100HV<sub>0.1</sub> micro-hardness is obtained. A nitride (white) zone is not observed on the surface – Figure 2a.

After introduction of 10% of gas corgon into the ammonia medium of the working chamber (Table 5, modes 3 and 4), a carbonitrided layer with higher surface micro-hardness (800–1180HV<sub>0.1</sub>) and total thickness (20–50  $\mu$ m) is obtained. At longer duration of the treatment (Table 5, mode 4) a layer with higher micro-hardness 1180HV<sub>0.1</sub>, and greater total thickness – 50 $\mu$ m – is formed on the surface of the 37Cr12Mn8Ni8MoVNb steel. Traces of a carbonitride zone are found in the layer – Figure 2.

Ion carbonitriding of 37Cr12Mn8Ni8MoVNb steel with higher pressure of the gas corgon ( $P_2 = 350$ Pa) and ammonia ( $P_1 = 350$ Pa) and time of treatment 2h leads to obtaining a layer with total thickness of 15 $\mu$ m and maximum surface micro-hardness 900HV<sub>0.1</sub>. With prolongation of the time of carbonitriding to 6h in the same saturation medium, the surface micro-hardness of the layer increases

to 1200HV<sub>0.1</sub> and its total thickness goes up to 30  $\mu$ m. A carbonitride zone is formed on the surface of the layer, which is 2  $\mu$ m thick – Figure 2.

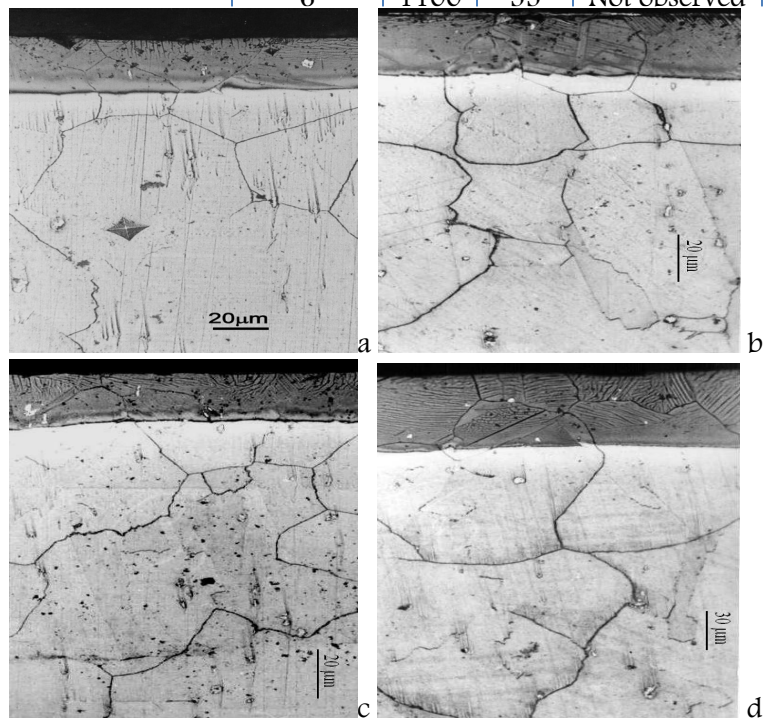
It can be noted that after ion nitriding and ion carbonitriding of 37Cr12Mn8Ni8MoVNb steel at the same mode of treatment (temperature 550 °C, total pressure of the two gases in the vacuum chamber 400Pa and time of treatment 4h), the surface micro-hardness is almost the same (1100–



**Figure 1.** Micro-structure of 37Cr12Mn8Ni8MoVNb steel after quenching and double tempering X500, a- tempering at 650 °C, b- tempering at 780°C

**Table 5.** Results from ion carbonitriding and ion nitriding of the steel

No of the mode in Table 3	37Cr12Mn8Ni8MoVNb		
	HV <sub>0.1</sub>	$\delta_{tot}$ $\mu$ m	$\delta_{c.z}$ $\mu$ m
1	900	15	Not observed
2	1200	30	2
3	800	20	Not observed
4	1180	50	traces
5	1100	40	traces
6	1100	55	Not observed



**Figure 2.** Micro-structure of 37Cr12Mn8Ni8MoVNb steel after treatment at  $t = 550$  °C: a-  $P_{NH_3} = 350$ Pa,  $P_{82\% Ar + 18\% CO_2} = 350$ Pa,  $\tau = 2$ h ; b-  $P_{NH_3} = 350$ Pa,  $P_{82\% Ar + 18\% CO_2} = 350$ Pa,  $\tau = 6$ h c-  $P_{NH_3} = 360$ Pa,  $P_{82\% Ar + 18\% CO_2} = 40$ Pa,  $\tau = 6$ h; d-  $P_{NH_3} = 400$ Pa,  $\tau = 4$ h

1180HV<sub>0.1</sub>). The low total thickness of the layers, obtained after nitriding and carbonitriding, is seen from Table 5. It is explained by the austenitic structure of the 37Cr12Mn8Ni8MoVNb steel, in which the coefficient of nitrogen and carbon diffusion is smaller.

After treating the 37Cr12Mn8Ni8MoVNb steel by an additionally introduced carbon-containing gas (corgon) in ammonia medium at different percentage ratio, carbonitrided layers with lower total thickness are obtained, compared to the layers, formed in the process of nitriding. This is due to the increased content of carbon on the surface, indirectly delivered from CO<sub>2</sub>. Apparently the availability of carbon on the surface impedes the diffusion of nitrogen in the interior of the metal. Only after conducting the process of ion carbonitriding at higher pressure - 700Pa – of both gases – corgon and ammonia (mode 4, Table 5) layers with carbonitride zone thickness of up to 22µm are obtained. Apparently ammonia and corgon pressure in the chamber plays an important role in delivering bigger amount of nitrogen and carbon on the surface for 6h time of carbonitriding. The metallographic analysis of the nitrided 37Cr12Mn8Ni8MoVNb steel does not detect the presence of white (connected) zone on the surface of the steel.

Counterparts and slip lines are well seen in the surface layer, which serve as intersections between the slip planes and the outer surfaces of the crystals. The availability of slip lines influences favorably nitrogen and carbon diffusion into the volume of the grains. [1].

## 5. CONCLUSIONS

5.1. It has been established that after ion carbonitriding of 37Cr12Mn8Ni8MoVNb steel at:  $t = 550^{\circ}\text{C}$ ;  $P_{\text{NH}_3} = 350\text{Pa}$ ;  $P_{\text{corgon}} = 350\text{Pa}$ ;  $\tau = 6\text{h}$ , a layer with highest surface hardness of 1200HV<sub>0.1</sub> and thickness of the combined zone 2 µm is formed.

5.2. It has been proved that at the same temperature and duration of treatment but for different composition of the saturating gas medium [NH<sub>3</sub>, (82 % Ar + 18 % CO<sub>2</sub>)], at total pressure of 400Pa, the formed layers after ion carbonitriding of 37Cr12Mn8Ni8MoVNb steel are with lower thickness and micro-hardness, compared to the layers formed after ion nitriding.

5.3. It has been established that during the process of ion nitriding layers without a combined zone are formed, while in the process of carbonitriding the combined zone reaches up to 2 µm.

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