

Investigation of Surface Layer Parameters After Carbonitration of 20CrMo Grade Steel

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Abstract. The influence of the carbonitration medium on the distribution of chemical elements (C, N) and the change in microhardness over the depth of the surface layer formed during carbonitration is considered. The carbonitration operation was performed in 2 stages. During the first stage, cementation was performed at a temperature of 950°C for 40 minutes in a C_2H_2 medium at a flow rate of 0.5 to 3.0 liters per minute. During the second stage, nitriding was performed in N_2 medium at a temperature of 850°C for 40 minutes at a constant nitrogen consumption of 1.5 liters per minute. Steel grade 20CrMo was used as the object of the study. It was shown that the carbonitration process of 20CrMo steel followed by high-frequency current quenching led to a significant increase in surface hardness. The distribution of chemical elements over the depth of the surface layer is not uniform: the carbon content changes gradually over the depth of the surface layer, while the presence of nitrogen is not fixed already at a depth of 200 μm .

Keywords: carbonitration, nitrogen, carbon, distribution, layer depth, microhardness.

Introduction

Thermochemical treatment is a common type of metal surface treatment in order to increase hardness, wear resistance, and corrosion resistance [1, 2, 3]. Thermochemical treatment is used for steels that cannot be hardened in the traditional way (quenching followed by tempering). Also, thermochemical treatment is used when volumetric quenching technology is not cost-effective for this type of parts. The most common types of thermochemical treatment are nitriding, cementation and carbonitration.

The analysis of literature sources has demonstrated that carbonitration technology is the most preferred method of thermochemical treatment. The carbonitration process can be carried out at a lower temperature compared to cementation technology. Also, unlike nitriding, the carbonitration process proceeds faster due to more active carbon diffusion. This increases the productivity of the equipment [4, 5, and 6].

An analysis of the results of the performed studies demonstrates that carbides of various natures are the primary phase that forms in the hardened layer during carbonitration, re-

gardless of the composition of the medium and temperature. This is due to a higher carbon diffusion coefficient compared to nitrogen diffusion [7, 8]. Therefore, two factors affect the distribution of elements over the depth of the hardened layer: the diffusion coefficient and the affinity of the elements to carbon and nitrogen. It is these two factors that will determine the kinetics of the distribution of elements over the depth of the reinforced layer.

The purpose of this study is to determine the influence of the composition of the medium on the kinetic features of the distribution of chemical elements and properties (microhardness) over the depth of the hardened layer during carbonitration.

Research methods

20CrMo grade steel was chosen as the object of the study, the steel composition is shown in Table 1.

20CrMo grade steel is a low carbon and low alloy steel. Chromium and molybdenum provide a high degree of hardenability. Since the carbon content is low, therefore, the hardening indicators are insignificant (a small increase in hardness values after the quenching operation). That is why these steels are subjected

Table 1 – Chemical composition and mechanical properties of steel grade 20CrMo (GOST 4543-2016)

Element content, % by weight									Mechanical properties			
C	Si	Mn	Cr	Mo	Ni	P	S	Fe	σ_B , MPa	σ_T , MPa	KCU, J/cm ²	hardness, HB
0.15-0.25	0.17-0.37	0.4-0.7	0.8-1.1	0.15-0.25	≤0.3	≤0.04	≤0.04	rest	780	590	88	179

to thermochemical treatment operations: cementation, nitriding or carbonitration. Their application creates a layer with a high content of carbon and nitrogen on the surface of steel. The increased content of these chemical elements in the surface layer contributes to the formation of martensite with a high carbon content and new phases of introduction such as complex carbides-nitrides. This increases the values of the hardness and wear resistance parameters of the surface.

After the application of thermochemical treatment operations, 20CrMo grade steel is used to manufacture parts operating in conditions of increased wear resistance: gears, shafts, fasteners, connecting rods, and others.

The carbonitration technology was carried out in two stages. The cementation process was carried out in a C_2H_2 medium during the first stage. The flow rate of C_2H_2 was changed from 0.5 to 3.0 liters per minute. The temperature of the process was 950°C with duration of 40 minutes. Nitriding in N_2 medium was performed during the second stage. The consumption of N_2 was constant and equal to 1.5 liters per minute. The temperature of the process was 850°C with duration of 40 minutes.

It should be noted that the parameters of the nitriding process were constant, while the parameters of the cementation process (namely, the composition of the medium) were changing.

The samples were quenched with high-frequency currents after completion of the carbonitration process. The duration of quenching was 30 seconds at a temperature of 780°C. Upon completion of quenching, the samples were cooled in oil and then tempering at a temperature of 550°C.

The values of hardness and microhardness parameters were measured after the experimental samples were completely cooled. The hardness of the surface layer was measured using a Willson 1150 instrument. Measurements were carried out at least 5 points. Microhardness profiles in the cross-section of the samples were obtained using a PMT-3 microhardness tester with a test load of 30 gs and a holding time of 15 seconds.

The carbon and nitrogen content in the

depth of the surface layer to be hardened was determined using an SDTM 30 energy dispersive attachment with a Si detector and a Jeol JCM – 7000 electron microscope.

Scientific results

The surface layer formed as a result of carbonitration of 20CrMo steel is shown in Figure 1.

Table 2 shows the results of measuring the hardness values of the surface layer depending on the composition of the medium and temperature. 20CrMo steel was used as a comparison sample after quenching with high-frequency currents followed by tempering at the same parameters.

Figure 2 shows that the composition of the applied medium (gas consumption) has a significant effect on the surface hardness. The higher the carbon content in the saturating medium, the higher the value of the hardness parameter. The increase in hardness can be explained by an increase in the carbon content in the surface layer due to the diffusion of carbon from the saturating gas. This leads to the transition of carbon to martensite during the quenching process. The resulting martensite has a higher degree of tetragonality and, consequently, a higher hardness.

However, as can be seen from the results

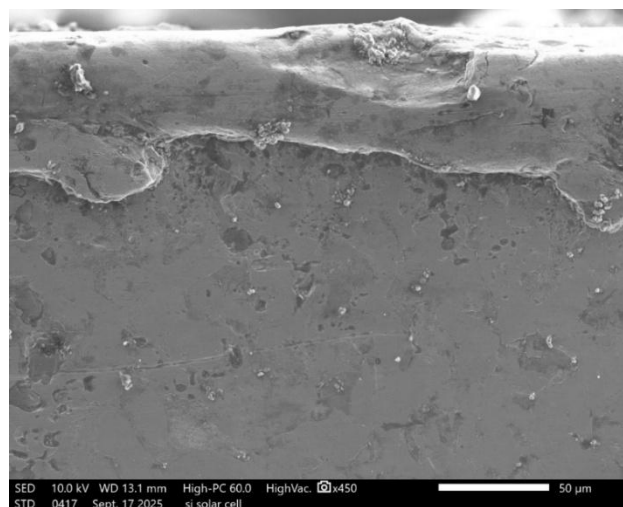
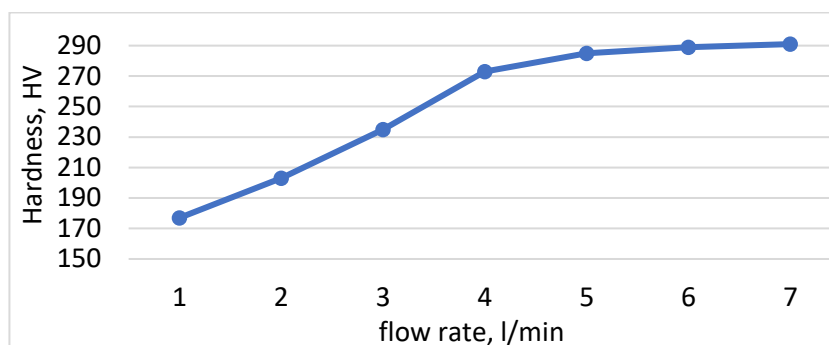


Figure 1 – Surface layer after carbonitration of 20CrMo steel (x400)

Table 2 – Results of measuring the hardness of 20CrMo steel after carbonitration and quenching

Sample No.	Flow rate C_2H_2 , l/min	Flow rate N_2 , l/min	Hardness of the surface layer, HV
0	0	0	177
1	0,5	1,5	203
2	1,0	1,5	235
3	1,5	1,5	273
4	2,0	1,5	285
5	2,5	1,5	289
6	3,0	1,5	291

**Figure 2 – Change in hardness depending on acetylene consumption**

obtained (Table 1, Figure 2), an increase in acetylene consumption to 3.0 liters per minute does not lead to a significant increase in hardness. This suggests that to achieve maximum hardness after carbonitration, it is necessary to limit the consumption of acetylene to 1.5-2.0 liters per minute with a nitrogen consumption of 1.5 liters per minute.

The carbon and nitrogen content in the depth of the reinforced layer was studied on experimental sample No. 4 (Figure 3). Acetylene consumption was 2.0 liters per minute.

The data in Figure 3 show kinetic features in the distribution of carbon and nitrogen over the depth of the surface layer during carbonitration. A gradual decrease in carbon content was observed. At a distance of 600 μm from the surface, the carbon content is still 1.5 times higher than in the main matrix (distance from the surface of 1000 μm). While the presence of nitrogen is not observed at a similar point. Such a difference in the kinetics of the distribution of elements indicates a higher diffusion coefficient of carbon compared to nitrogen. In addition, the nitriding process follows after the cementation process, respectively, the carbon atoms have already occupied the "available free places", therefore, and nitrogen diffusion requires higher activation energy.

The results of scientific studies [5, 9] demonstrate that nitrogen is present in the

complex solid phase of the type $\epsilon\text{-Fe}_{2-3}(\text{N}, \text{C})$ at the end of the carbonitration process. This leads to an increase in hardness values. The authors note that such phases are present mainly on the surface. Such phases are not observed at a depth of 400 μm .

It can be assumed that a change in the carbon and nitrogen content along the depth of the surface layer should cause a change in the microhardness values. Figure 4 shows data on the change in microhardness depending on the depth on sample No. 4.

The values of the microhardness parameter decrease significantly at a distance of 300 μm . The values of the microhardness parameter at a depth of 500 μm become the same as the values of the microhardness of the sample matrix.

Based on the results obtained, it can be assumed that the most effective layer depth is 200-300 μm . To increase the depth of the layer, it is necessary to activate the diffusion of carbon and nitrogen. Apparently, this can be achieved by changing the parameters of the carbonitration process.

Conclusions

1. The carbonitration process of 20CrMo grade steel with subsequent treatment with high frequency currents, quenching and tempering leads to a significant increase in surface hardness. 20CrMo grade steel without carbonitration has a hardness of 177HV, while the

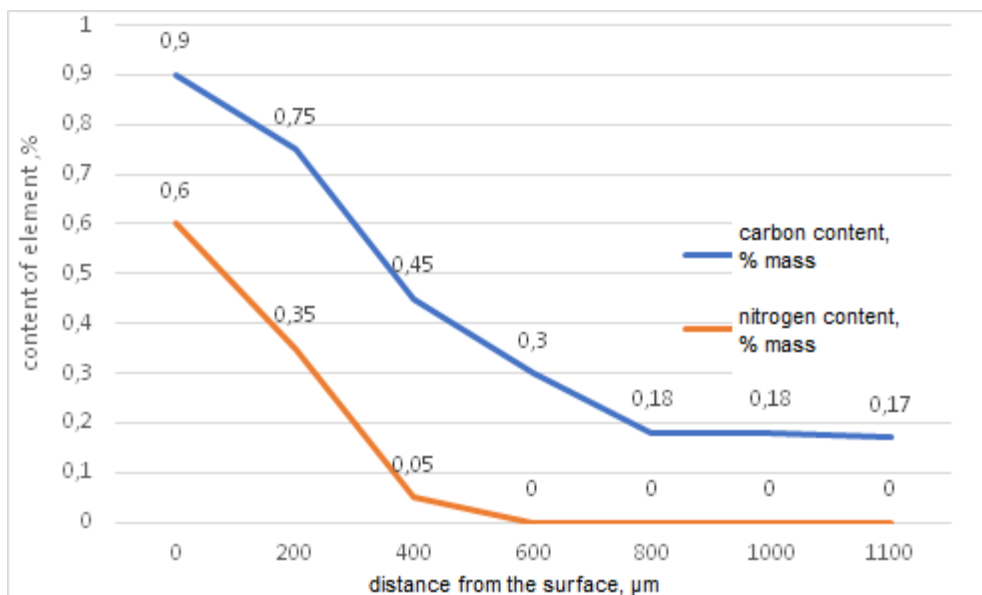


Figure 3 – Changes in carbon and nitrogen content over the depth of the surface layer

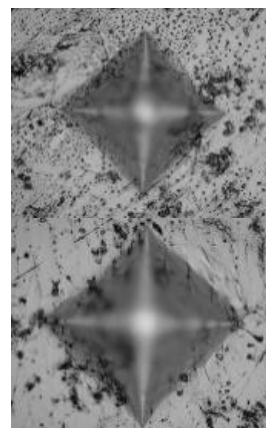
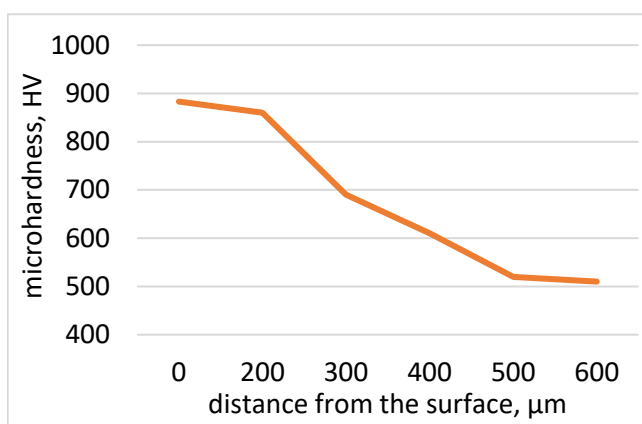


Figure 4 – Change in microhardness by layer depth

prototypes demonstrate hardness up to 290 HV. The increase is about 40%.

2. The following values of the parameters of the composition of the saturating medium of the carbonitration process are determined as optimal for 20CrMo grade steel: acetylene consumption of 1.5-2.0 liters per minute at a temperature of 950°C; nitrogen consumption of liters per minute at a temperature of 850°C.

3. The distribution of microhardness over the depth of the layer has a monotonously decreasing character. The decrease in microhardness values is almost extreme at a depth of 200 μm. The microhardness value becomes comparable to the microhardness of the matrix at a depth of 500 μm.

4. The kinetic features of the distribution of carbon and nitrogen over the depth of the

hardened layer after the carbonitration process of 20XM steel were studied. The research results have shown that the carbon distribution over the layer profile has a monotonously decreasing character. The carbon content is 0.9% on the surface. The carbon content at a depth of about 800 μm becomes almost the same as in the matrix (0.17%). The nitrogen content varies dramatically: approximately 0.6% on the surface. The nitrogen content decreases by a factor of 2 at a layer depth of 200 μm and is practically not observed further.

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20ХМ маркалы болат карбонитрациясынан кейін беткі қабаттың параметрлерін зерттеу

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Аңдатпа. Карбонитрациядағы ортаның химиялық элементтердің (C, N) таралуына және карбонитрация процесінде пайда болған беткі қабаттың тереңдігі бойынша микроқаттылықтың өзгеруіне әсері қарастырылады. Карбонитрация операциясы 2 кезеңде жүргізілді. Бірінші кезеңде цементтеу 950°C температурада C₂H₂ ортасында 40 минут ішінде минутына 0,5-тен 3,0 литрге дейін жүргізілді. Екінші кезең процесінде N₂ ортасында 850°C температурада минутына 1,5 литр азотты тұрақты тұтыну кезінде 40 минут бойы азоттау жасалды. Зерттеу нысаны ретінде 20ХМ маркалы болат пайдаланылды. 20ХМ маркалы болатты карбонитрациялау процесі, содан кейін жоғары жиілікті токтармен қатайту бетінің қаттылығының айтарлықтай жоғарылауына әкелетіні көрсетілген. Химиялық элементтердің беткі қабаттың тереңдігі бойынша таралуы біркелкі емес: көміртегі мөлшері беткі қабаттың тереңдігі бойынша біртіндеп өзгереді, ал азоттың болуы 200 мкм тереңдікте бекітілмейді.

Кілт сөздер: карбонитрация, азот, көміртек, таралу, қабат тереңдігі, микроқаттылық.

Исследование параметров поверхностного слоя после карбонитрации стали марки 20ХМ

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Аннотация. Рассмотрено влияние среды при карбонитрации на распределение химических элементов (C, N) и изменение микротвердости по глубине поверхностного слоя, образовавшегося в процессе карбонитрации. Операцию карбонитрации проводили в 2 этапа. В течение первого этапа выполнили цементацию при температуре 950°C в течение 40 минут в среде C_2H_2 при расходе от 0,5 до 3,0 литров в минуту. В процессе второго этапа сделали азотирование в среде N_2 при температуре 850°C в течение 40 минут при постоянном расходе азота 1,5 литров в минуту. В качестве объекта исследования была использована сталь марки 20ХМ. Было показано, что процесс карбонитрации стали марки 20ХМ с последующей закалкой токами высокой частоты привел к значительному повышению твердости поверхности. Распределение химических элементов по глубине поверхностного слоя носит неодинаковый характер: содержание углерода меняется постепенно по глубине поверхностного слоя, в то время как присутствие азота не фиксируется уже на глубине 200 мкм.

Ключевые слова: карбонитрация, азот, углерод, распределение, глубина слоя, микротвердость.

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