TECHNOLOGICAL FEATURES OF CEMENTATION OF LOW-ALLOY STRUCTURAL STEEL

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Abstract - This article presents the results of studies on the structure formation of alloyed structural steels during the carburization process. A feature of the study of the structure formation process is that medium-carbon steels with a carbon content of 0.4 - 0.55% were chosen as research objects, while steels with a carbon content of 0.3% are mainly studied. A new scheme for strengthening structural steels has been proposed by combining the process of carburization with high-temperature hardening. As a result, it was possible to obtain a surface layer of low-alloy structural steel consisting of fine-needle martensite and small areas of retained austenite and carbides. At the same time, as a result of high-temperature hardening, the defectiveness of the crystalline structure of 40XN steel increased by 1.3 times compared to the defectiveness of the crystalline structure after generally accepted hardening modes for this grade of steel, and the hardness of the surface cemented layer increased from HRC 56-57 to HRC 60-62.

Keywords: Carburization, Carbon low-alloy steel, Hardening, Tempering, Hardness.

1. Introduction

Currently, carburization is the most common technological process in mechanical engineering to obtain high hardness and wear resistance of parts. The advantage of the method is its high manufacturability, thanks to which the cementation process can be carried out both at machine-building plants and in repair shops of any level. The standard carburization process provides carburization of the steel surface to a carbon concentration (0.8 - 0.9% C). An increase in the content of the carbide phase in steel can only be achieved through the additional formation of cementite. The content of carbides of alloying elements is limited by the percentage of these alloying elements. In a number of works [1, 2], the possibility of saturation with carbides by carburization of steels with a carbon content from 0.4 to 0.9% C was investigated. In particular, when carburizing steel ShKh15, it was possible to obtain a cementite component of up to 90%, thereby ensuring high wear resistance of the steel without heat treatment. When studying the cementite layer [3, 4], it was found that the composition of cementite depends on the carbon content in the steel and varies depending on the saturation temperature. It is shown in [5] that cementite is an octahedron with iron atoms at the vertices and a carbon atom in the center, and cementite is characterized by anisotropy of physical properties.

The coefficient of thermal expansion of cementite differs little from the thermal expansion of austenite and has an anomalous expansion along the "C" axis [6]. It has also been established that the best carbide formation is obtained in steels alloyed with chromium. Chromium ensures the formation of granular cementite during carburization of alloy steels. The carbide content in cementite can be obtained as much as possible [7-10].

For different groups of complex alloy steels, especially chromium-nickel steels, the optimum saturation degree for the same types of destruction is not the same. Not all methods of carburization meet modern requirements. Only those processes in which it is possible to regulate saturation by maintaining a given carbon potential sufficiently constant should be considered in promising technological processes of heat treatment [11-14]. Therefore, when processing heavily loaded parts, it is advisable not only to carburize in solid carburizers, but also gas carburizing using gases rich in hydrocarbons: methane, butane, propane. In cases where it is mainly necessary to increase wear resistance, it is advisable to carry out local carburizing using solid carburizers and solid coatings [15-17].

2. Methodology

Steel grades 40XN and 50 XN were chosen as objects of study. The chemical composition of steel is presented in Table 1. Cementation of steels was carried out in a closed container loaded into cementation chamber 3. Steel samples were placed on top of the carburizer layer, which were covered with carburizer on top. The process of carburization and subsequent high-temperature hardening was carried out according to the scheme (Fig. 1).

Table 1: Chemical composition, %

Steel grade	C	Si	Mn	Cr	Ni	P	S
40XN	0,4	0,31	0,72	0,75	1,2	0,03	0,03
50XN	0,52	0,32	0,68	0,72	1,4	0,03	0,03

The cementation process was carried out in a special steel box (Fig. 2). A carburizer consisting of DG-100-80% grade soot crushed to 3-20% was poured onto the bottom of the box. Samples were placed on top of the carburizer layer, which were covered with carburizer, as well as layer by layer. Gas soot is the main carbon-containing component used in 3 - is a catalyst also widely used in carburization technology [11-15].

The carburization temperature was 900-1200 °C for all grades of steel, holding at the temperature varied from 2 to 12 hours. After carburization, heat treatment of the samples was carried out, which included hardening from the appropriate temperatures for each grade of steel and low-temperature tempering in the temperature range of 200-400 °C.

Microstructural analysis was performed using an Oxion Inverso OX 2653-PLM microscope. Microscopic sections were analyzed after a full cycle of cementation and heat treatment. The prepared microsections were etched in a 4% solution of nitric acid in ethyl alcohol.

X-ray structural analysis was performed on a DRON-2.0 X-ray diffractometer using iron anode radiation. The survey was performed depending on the object of study, either in the step scanning mode or in the automatic recording mode on a chart tape. With step scanning, the surveys were as follows: voltage V = 35 kV; anode current J = 9 ma, scanning step 0.1^0, exposure 40 sec, slits limiting horizontal divergence 2 mm, vertical 6 mm, at the counter 1 mm.

When shooting in the automatic recording mode, the modes were selected in such a way as to ensure a sufficiently high rarefaction capacity of the analysis method. This was achieved at a voltage of V = 30 ÷ 35 kV, J = 9 ma, the counter movement speed from 0.25 to 1 min, the tape diagram speed from 720 to 1800 mm/hour. The width of the X-ray lines was determined at half the maximum height, as the arithmetic mean of five to six diffractograms or X-ray intensity distribution curves. Calculations of measurement errors showed that they are within 5-10% depending on the object of study. Calculations of the physical width of the X-ray interference line were carried out using the approximation method.

The amount of residual austenite was determined by determining the intensity ratio of the lines (211) of the α phase and (200) of the γ phase.

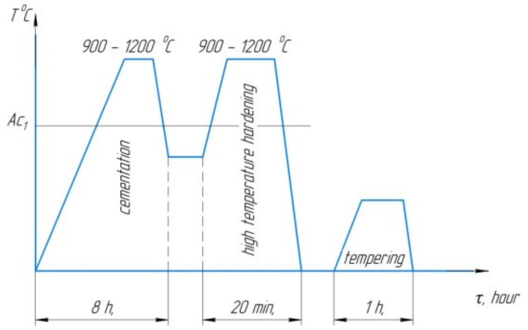

Figure 1: Scheme of carburization and subsequent heat treatment

The hardness of the cement bath layers was determined using a Rockwell hardness tester TK-2 under a load of 150 kgf. Impact toughness was determined on a pendulum impact tester on samples of dimensions 10x10x55 according to GOST 9454-78.

The abrasive wear resistance of the steels under study was tested on a XCH-B machine. This method involves testing for abrasive wear.

Cylindrical samples with a diameter of 2 mm and a length of 20 mm were made for testing. The cylindrical sample was installed vertically on the machine and when rotating, the disk with a stretched abrasive skin receives a radial movement, which one revolution of the disk is 1 mm. In fact, the sample moves along the Archimedes spiral. Friction of the sample occurs on a fresh surface at a low sliding speed and intensive wear.

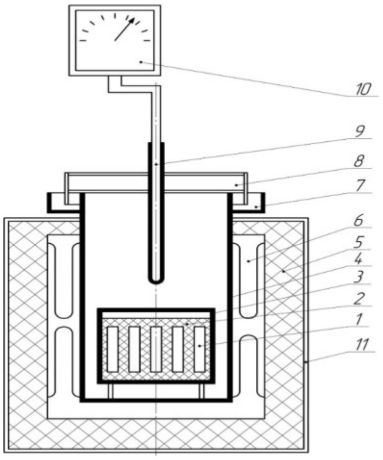

Figure 2: Scheme of laboratory cementation of the furnace: 1 – samples; 2 – carburizer; 3 – container with a lid; 4 – furnace muffle; 5 – lining; 6 – heaters; 7 – sand gate; 8 – furnace cover; 9 – thermocouple; 10 – electronic potentiometer; 11 – furnace casing

3. Research Results

The depth of the diffusion zone, the defectiveness of the crystal structure, and the hardness of the resulting surface layer were studied. The defectiveness of the crystalline structure was studied using X-ray analysis by measuring the width of the X-ray line (220) as an integral characteristic of the defectiveness of the crystalline structure of steels.

Studies of the level of defects in the crystalline structure of steels 40XN and 57XN have shown that under the regimes of carburization and hardening temperatures of 1000 – 1100 °C, the calculation shows the level of defects in the crystalline structure (Fig. 3).

The depth of the carburized layer of steels was measured after carburization at various temperatures for 8 hours (Fig. 4).

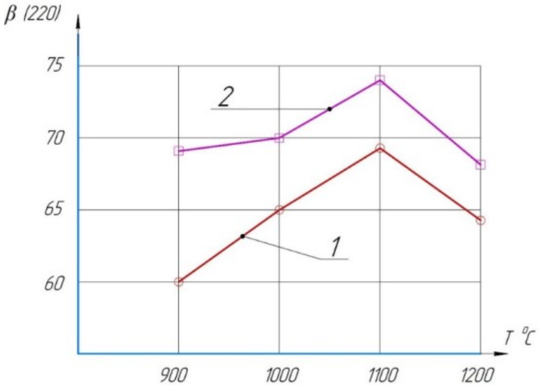

Figure 3: The influence of the temperature of carburization and subsequent hardening on the width of the X-ray line (220) tempering 200 °C. 1 – steel 40XN; 2 – steel 50XN

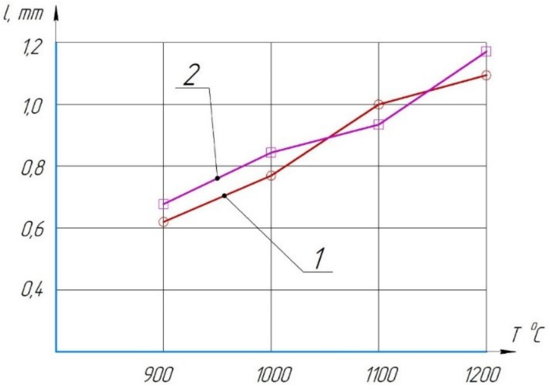

Figure 4: Influence of carburization temperature of steels on the carburized layer. Exposure 8 hours: 1 – steel 40XN; 2 – steel 50XN

The main working indicator of a cemented steel layer is hardness. For this purpose, measurements of the hardness of the surface layer were carried out after the cementation process at various temperatures, combined with the hardening process (Fig. 1). As measurements of the hardness of the steels under study showed, the hardness values of cemented structural steels reached the instrumental level in the region of HRC 60 – 62 (Fig. 5).

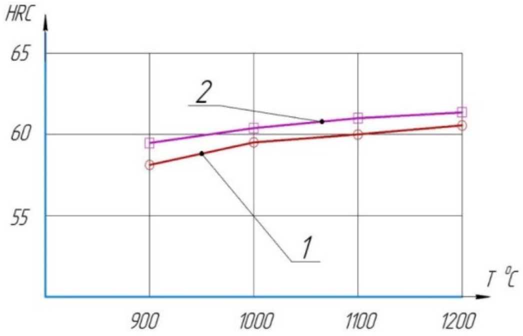

Figure 5: Influence of carburization temperature and subsequent hardening on the hardness of steel tempered at 200 °C. 1 – steel 40XN; 2 – steel 50XN

Analysis of the microstructure of the surface layer showed that after carrying out the processes of carburization and subsequent hardening at a temperature of 1000-1100 °C followed by tempering at 200 °C, it is possible to obtain a structure consisting of martensite with retained austenite and carbides, which corresponds to the structure of tool steels (Fig. 6).

Figure 6: Microstructure of 40XN steel carburized at 1000 °C for 8 hours, followed by quenching and tempering at 200 °C

To conduct tests for abrasive wear resistance of the steels under study, samples of 40XN and 50XN steels were prepared using the new technology. The samples were hardened using the following technology: first, the process of carburization was carried out in a solid carburizer consisting of 80% carbon black and 20% barium carbonate at temperatures from 900 to 1200 °C for 8 hours. Then the samples were removed from the carburizing box and cooled to a temperature of 500 °C and immediately transferred to the same hardening furnace where carburization was carried out. They were heated to a temperature of 1100 °C and quenched in oil and tempered at a temperature of 200 °C. The results on the wear resistance of the samples are presented in Fig. 7.

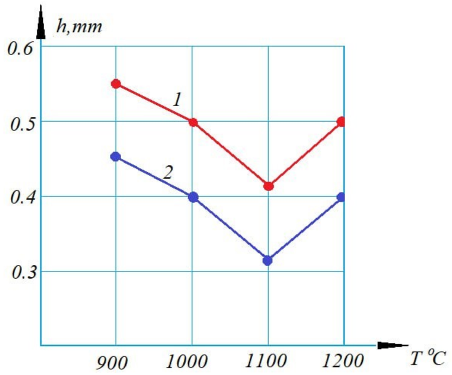

Fig.7: Change in the wear value of steels depending on the temperature of carburization and hardening, tempering 200 °C. 1-Steel 40XN; 2- Steel 50 XN

As can be seen from the graph (Fig. 8), the lowest wear is observed in steel samples subjected to carburization and hardening from a temperature of 1100 °C. It is also clear that the main factor in increasing the wear resistance of steels during carburization and subsequent heat treatment is the percentage content of carbon, which is the main element in the process of carburization of steels.

4. Discussion

To obtain high strength and hardness in steels, there are several processing methods: hardening with low tempering, chemist technology, heat treatment, thermomechanical processing. Hardening with low tempering at a carbon content of up to 0.45-0.5% leads to an increase in hardness and strength while maintaining ductility. With a further increase in carbon content, hardness increases, tensile strength decreases, and toughness decreases. When alloying steels, the hardenability increases and it is possible to achieve higher ductility and toughness of the steel. In general, modern structural steels are characterized by economical alloying with a carbon content of 0.4 to 0.5%, which makes it possible to obtain a structure over the entire cross-section of the product. In the standard process of carburization of carbon steel, cementite forms along the boundaries of austenite grains in the form of a cement network to obtain isolated carbides, it is necessary for cementite to be released in the form of grains; such a process is possible when alloying the steel with the ability of the leading elements to dissolve according to the ability to form carbide; it has the greatest means for carbon also elements; however These elements do not contribute to the formation of granular 1.1% chromium during the carburization process, granular particles up to 5 microns in size are formed. At the same time, it was recorded that with an increase in the chromium content in steel, the sizes of carbides decrease, and the total content of carbide in the cement layer increases. Previously conducted studies [8] found that when carrying out double-phase heat treatment during crystallization, the first hardening is carried out at a temperature of 1100 - 1150 °C degrees with an increase in the defectiveness of the crystalline structure of the steel, which in turn leads to an increase in wear resistance. It is shown that the defectiveness of the crystal structure increases due to the dissolution of impurity phases, leading to the formation of this structure upon cooling. This circumstance is confirmed by the results of a study on the influence of the temperature of carburization and subsequent hardening on the defectiveness of the crystalline structure. Saturation of the surface layer with atomic carbon of steel 40XN and 50XN makes it possible to obtain a high level of hardness after quenching due to the formation of cementite and additional dissolution of carbon in the γ - phase, which during the quenching process leads to the growth of the martensitic phase, and during the tempering process to the additional formation of chromium carbide, which generally leads to an increase in the hardness of the surface layer.

5. Conclusions

High-temperature carburization and subsequent hardening of low-alloy structural steels makes it possible to obtain a surface layer comparable in hardness to tool steels;

Carrying out high-temperature carburization and hardening with low tempering leads to an increase in the defectiveness of the crystalline structure of steel;

For high-temperature carburization, a solid carburizer based on gas soot and barium carbonate can be recommended.

For the process of carburization of steels and subsequent heat treatment in order to increase wear resistance, the percentage content of carbon in the steel has a decisive influence.

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