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EFFECT OF TREATMENT TEMPERATURE ON STRUCTURE FORMATION IN CR-MO-V STEEL

Abstract. *Properly selected heat treatment, which have the purpose to create a structure that would satisfy the requirements of the manufacturer, is the main way to improve the quality characteristics of the steel. The investigated steel 31CrMoV9 was heated to temperatures in the range of 850-1050°C and cooled in water and air. The structure consisted of bainite and martensite with different ratios, after normalization. An increase in the heating temperature leads to an increase in the amount of martensite from 5-10% at 850°C to 50% at 1050°C, that was shown by investigation. The microhardness of the steel increases respectively. The structure of the 31CrMoV9 steel consists of the tempered martensite, which is characterized by various morphology, after heating to different temperatures, quenching and tempering. Average of the microhardness of the steel decreases with an increase in quenching temperature. The change of the microhardness is probably due to an increase in the volume of residual austenite and the dissolution of alloyed carbides. Detected that with an increase in the heating temperature, an increase in the initial austenite grain led to the enlargement of martensite needle. Determined, that with increasing heating temperature, the dispersion of pearlite depends on the size of austenitic grains. An increase in the austenization temperature leads to an increase in the interplate distance. The alloy steel should be heated at the temperature of 850°C to obtain the uniform structure.*

Keywords: *alloy steel, heating temperature, structure, grain size, bainite, martensite, heat treatment, quenching, normalization*

Introduction.

Structural steels alloyed by chromium, molybdenum and vanadium are widely used in the various of the industries to manufacture critical products that operate under high pressure and temperature conditions [1]. Such alloying allows to harden

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products of larger cross-sections at lower cooling rates. The size of the austenite grain in the steel significantly depends on the heating temperature during heat treatment, which in turn affects the final structure of the steel and mechanical properties after treatment [2, 3]. Often, the malfunctions on the production line associated with a violation of the temperature and time treatment regime lead to excessive heating of metal products. One of the consequences of this is obtaining products with a change in the size of the initial austenite grains. Therefore, studying of the effect of austenization temperature on structure formation in 31CrMoV9 alloy steel is represents the interest.

Literature Review.

The technology for the production of alloy structural rolled products is a complex of the operations to give it the required properties (mechanical, technological) and form. The size of the steel grain significantly affects the complex of mechanical properties (plasticity, viscosity and hardness) [4, 5], with an increase in the austenite grain size, the intensity of wear increases [6]. In [4] showed, that the average increase in the size of the grains of the previous austenite is equal to 0,008 mm per 100°C increase in the austenization temperature. Research [5] of the Cr-Mo-V high-alloy steel was provided, that temperature range from 1010°C to 1070°C, the average diameters remain within the same grain size class, and at a temperature of 1100°C was observed a significant growth of the grains [5]. In [6] showed, that after austenitization at 950°C, an abnormal grain growth occurs.

The larger the grain, the more susceptible the steel is to quenching cracks and deformation, and the grain size greatly reduces the structural strength and the impact strength [7]. In [8] shows that an average grain size of more than 0,04 mm is not preferable for alloy steel in automotive industry. And for carbon alloy steels [9], abnormal grain growth is observed in the temperature range of 1000-1100°C

Research Methodology.

The research was conducted on the samples of the 31CrMoV9 steel, the chemical composition of which (Table 1) corresponded to EN 10085:2001 [10]. The samples were heated in a furnace to temperatures of 850°C, 950°C and 1050°C with a holding time of 30 min and subsequent cooling in water (quenching), in air (normalization) and in a furnace (annealing).

Table 1

Chemical composition of the steel 31CrMoV9

Designation, % by mass.	C	Si max	Mn	Cr	Mo	V	P max	S max
The experimental sample	0,33	0,25	0,59	2,59	0,23	0,11	0,011	0,025
EN 10085:2001	0,27-0,34	0,17-0,37	0,40-0,70	2,30-2,70	0,15–0,25	0,06–0,12	0,025	0,035

After quenching, the samples were tempered at 250°C for 1 hour and then cooled in air. The microstructure was studied using an Axiovert 200M MAT optical microscope after etching with an alcohol solution of nitric acid. The austenite grain size was determined by measuring the chord length after etching with a solution of picric acid. The microhardness was measured with Vickers micro hardness tester, type PMT3, test load 100 g.

Results

By research of the grain size determination of the austenite from the investigated steel was provided, that the steel is characterized by the variety of grains (Fig. 1). An increase in the austenitizing temperature increased the number of large grains. In general, the grain size of the austenite of the investigated steel increased by 25-35%.

Established, that 31CrMoV9 steel is characterized by a significant increase in the size of the austenite grain when heated from a temperature of 950°C. Investigated steel has a multigrain structure, with a conditional grain diameter in the range of 0.028-0.063 mm at a heating temperature of 850°C, 0.033-0.079 mm at 950°C, and 0.035-0.084 mm at 1050°C. The research results showed that the size of the austenite grain increases with increasing austenitization temperature, which can lead to a change in the structure of the test steel after heat treatment. With an increase in the austenitization temperature, the effect of the thermal factor is manifested, as a result of which the actual cooling rate of steel increases [11].

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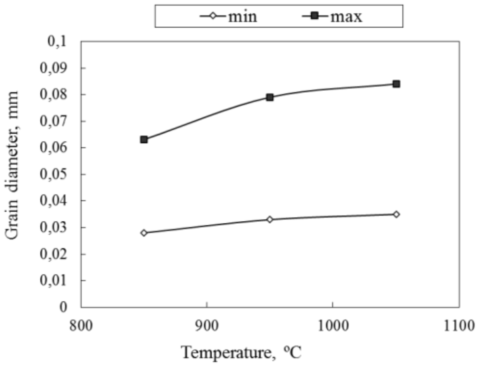

Figure 1 – Changing of the austenite grain size with increasing heating temperature

The increase in the grain size is associated with secondary recrystallization, which occurs as a result of the dissolution of dispersed (5÷20 nm) particles of the carbide phases that restrained grain growth. In this case, with increasing temperature, special vanadium carbides dissolve [11].

During assigning setting of the heat treatment regime for chromium, molybdenum and vanadium-alloyed steel, the temperature of the sharp increase in the grain size should be avoided. Otherwise, the structure can have a large grain size dispersion, which leads to a decrease in mechanical properties.

Investigated, the influence of the austenite grain growth on structure formation in 31CrMoV9 steel during heating to different austenization temperatures and cooling at different rates under different conditions.

After heating to different temperatures in the range of 850-1050°C and cooling in air, the structure of the experimental steel 31CrMoV9 consists of bainite, martensite, and excess alloyed carbides (Fig. 2). After normalization from temperature 850°C, the percentage of martensite was 5-10%. Martensite is non-needle-like (light areas in Fig. 2), it has the form of small grains with no characteristic needle-like structure, and no clear boundaries between martensite crystals are observed. The average microhardness of the steel is 3340 MPa. The alloying elements induce liquidation (striping), which begins to appear when cooled from a higher heating temperature of 950°C (Fig. 2, b). Small excess alloyed carbides are also observed in the steel structure. With an increase in the normalization temperature under equal cooling conditions, the amount of martensite formed increases. This is mainly due to an increase in the total area occupied by martensite

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without changing its morphology. Increasing the temperature to 1050°C resulted in the formation of about 50% of martensite, in addition to bainite (Fig. 2, c).

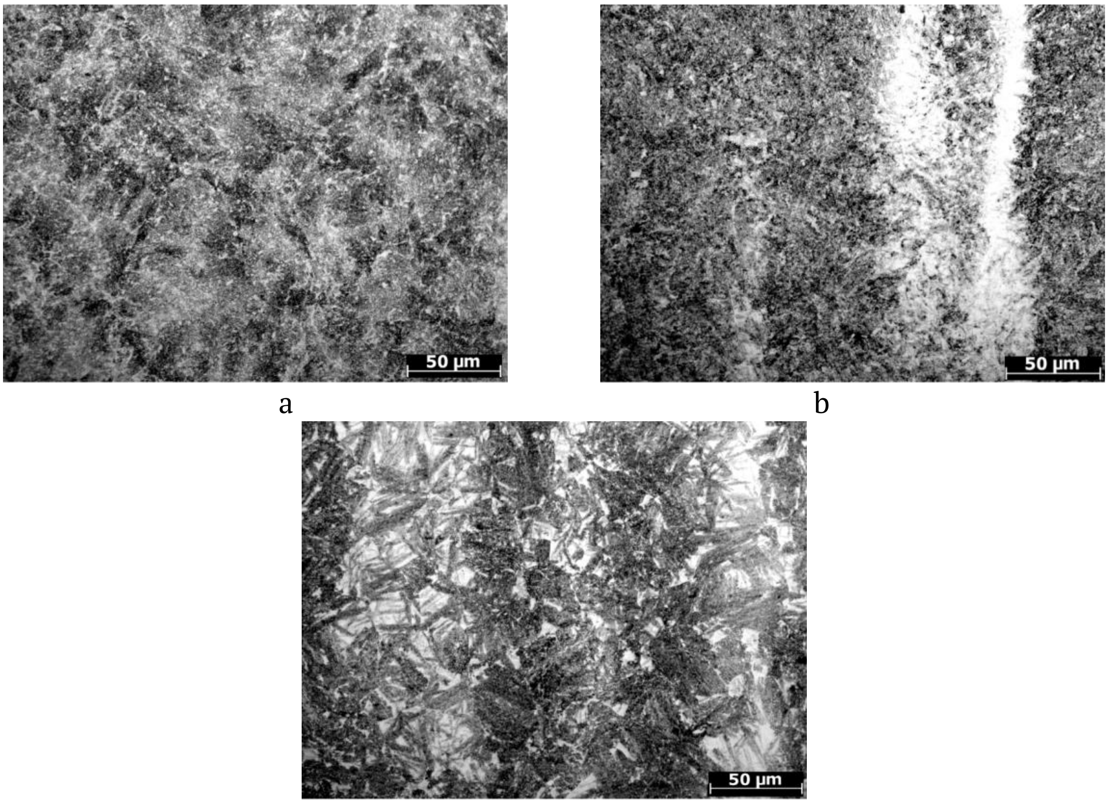

Figure 2 – Structure of the 31CrMoV9 steel after normalization from 850°C (a), 950°C (b) and 1050°C (c)

The light areas of non-needle-like martensite look like grains and stripes. The average microhardness of the sample heated to 1050°C increased to 4075 MPa (Fig. 3). Changes in the size of the austenitic grains can be reflected in the martensitic structure obtained during final heat treatment. Changes in the morphology of the martensite affect the reduction of mechanical properties: impact strength, yield strength, hardness, etc. Therefore, the effect of the increasing the austenitizing temperature on the martensitic structure of the 31CrMoV9 steel was investigated. After heating to different temperatures, quenching, and tempering, the structure of Cr-Mo-V steel consists of the tempered martensite (including residual austenite and decomposition products of residual austenite) and alloyed carbides (Fig. 3).

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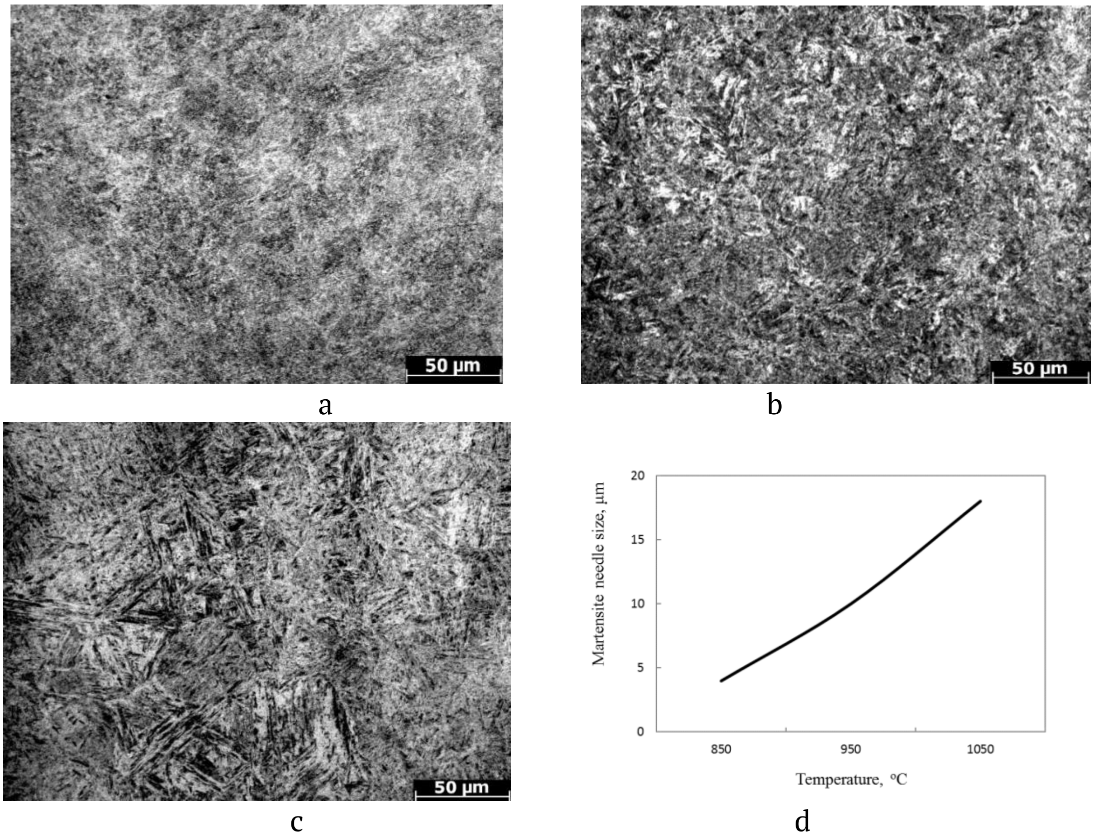


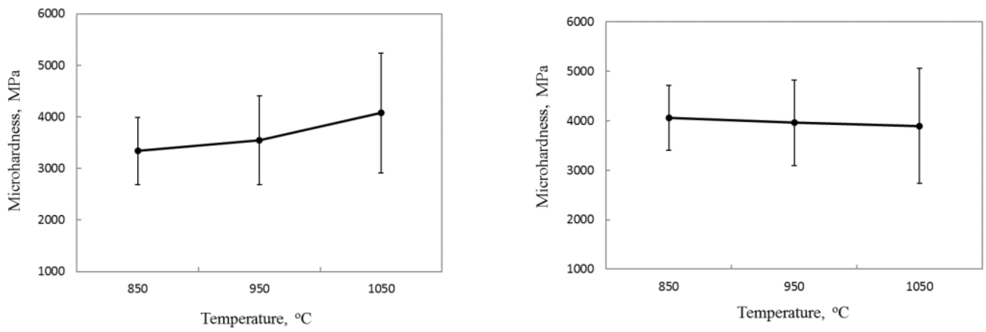
Figure 3 – Structure of the 31CrMoV9 steel after quenching from 850°C (a), 950°C (b) and 1050°C (c) and tempering; d - middle size of the martensite needle after quenching at different heating temperatures

A significant enlargement of martensite with increasing temperature is observed. It is known that the size of martensite plates (needle size) depends on the size of the prior austenite grains: the larger the austenite grains, the more needle-shaped the martensite is formed. The size of martensite needles after quenching from 850°C is approximately 4 µm, from 950°C is 10 µm, and for quenching from 1050°C is 18 µm (Fig. 3, d). The size of the austenitic grain affects the martensitic transformation due to the nucleation density provided by the grain boundary zone and due to the strengthening of the austenitic phase as the transformation progresses [12].

In addition, the solubility of excess vanadium carbides [13] in steel increases with increasing heating temperature, and their amount decreases significantly when heated to 1050°C (see Fig. 2-3, c).

Although the microhardness of the liquefaction areas increases with increasing quenching temperature, the overall average microhardness of the steel decreases (Fig. 4, b), unlike the steel cooled in air (Fig. 4, a).

In Cr-Mo-V steel, vanadium carbide is released in a very finely dispersed granular form. Since vanadium forms difficult to dissolve carbides, at the traditional quenching temperatures of 800-900°C, it remains bound in carbides and does not transform into austenite. This also affects the change in microhardness of the investigated steel.



a b

Figure 4 – Microhardness of the 31CrMoV9 steel after normalization (a) and quenching (b) at different heating temperatures

The average microhardness values of the 31CrMoV9 steel after quenching and tempering were: 4060 MPa for 850°C, 3960 MPa for 950°C, and 3894 MPa for 1050°C. Such a change in microhardness is probably due to an increase in the amount of residual austenite, since an increase in the quenching temperature increases the amount and degree of metastability of residual austenite, its enrichment with carbon and alloying elements due to the dissolution of alloyed carbides. In addition, an increase in the quenching temperature, and hence an increase in the degree of solubility of carbides in austenite, causes a decrease in the temperature of the onset of martensite transformation and, as a result, an increase in the amount of residual austenite.

The results, which were obtained in [14], shown that as the holding time or temperature increases, the initial average diameter of the austenite increases, as well as the size of blocks and packets in the martensite. This affects the mechanical

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properties because a smaller grain has more blocks and packets and the higher density of the dislocations in relation to the same area. When heated to 1050°C and cooled in air and water, the widest interval between the minimum and maximum microhardness values of structural components is observed, which may further adversely affect the properties of this steel.

The dispersion of the pearlite in the carbon steels depends on the austenitization temperature and, accordingly, the size of the austenite grain, it is known [15]. An increase in the austenitizing temperature of thr steel leads to an increase in grain size and the formation of more special boundaries, which leads to an increase in pearlite dispersion and austenite stability. All samples of the 31CrMoV9 steel heated to 850-1050°C and cooled at rate of ~0.05°C/s have a ferrite-pearlite structure. A large amount of the excess carbides of the alloying elements is observed in the structure of the steel heated to 850°C (Fig. 5, a).

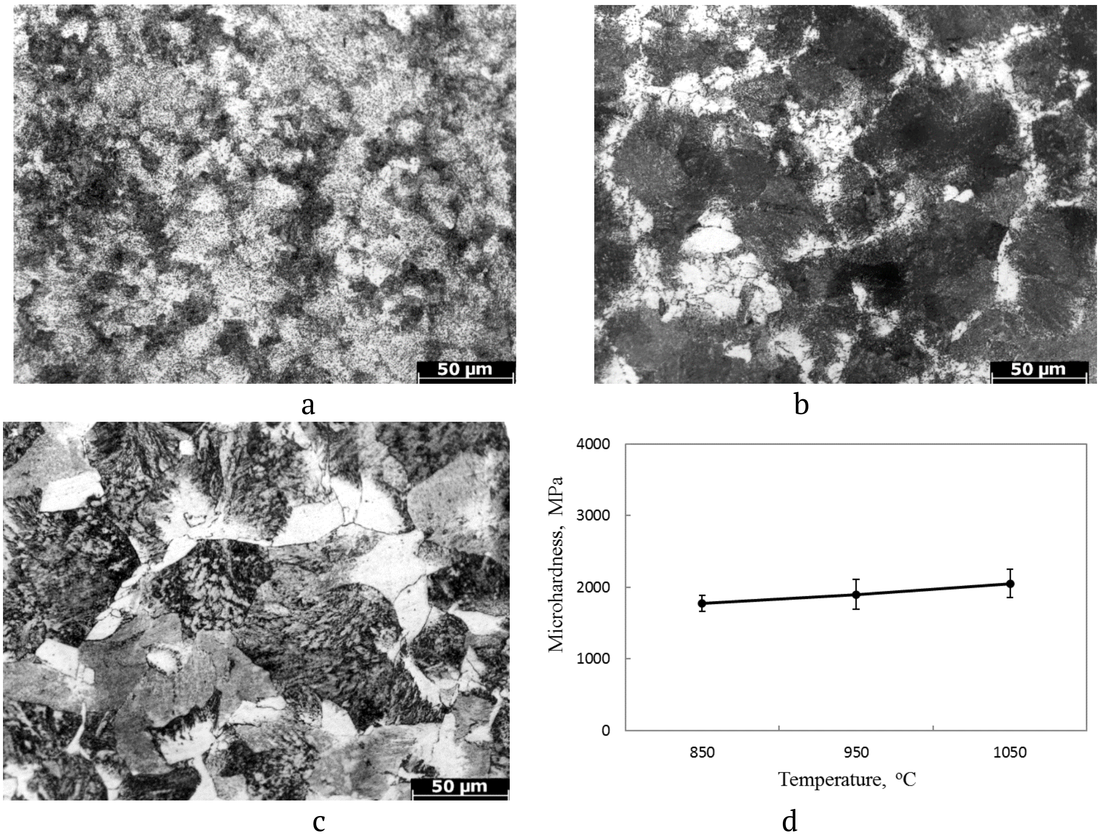

Figure 5 – The structure and microhardness (d) of the 31CrMoV9 steel after slow cooling from temperatures of 850°C (a), 950°C (b), 1050°C (c)

With an increase in the austenitizing temperature to 1050°C, most of the carbides dissolve (Fig. 5, c). The average grain size of the pearlite increases with increasing austenitization temperature and is 0.019 mm for 850°C, 0.047 mm for 950°C, and 0.088 mm for 1050°C. An increase in the austenitizing temperature also leads to change in the dispersion of the pearlite, i.e. an increase in the inter-plate distance. Researched, that the inter-plate distance in pearlite increases from 0.25 µm to 0.95 µm. The smallest deviation in the microhardness values is observed after heating to 850°C and slow cooling with an oven. Therefore, during increases the heating temperature, the actual cooling rate may differ from that predicted by the thermokinetic diagram. This should be taken into account when setting the heat treatment regimes for alloy steel. With an increase in the austenitizing temperature, the microhardness of the alloy steel increases (Fig. 5, d), which is caused by the dissolution of the small carbides of the alloying elements and their enrichment of cementite in the pearlite composition.

Investigated the mechanical properties of the 31CrMoV9 steel after treatment according to the standard quenching regime with austenitizing at 850°C. The industrial steel billet 31CrMoV9 had a diameter of 120 mm. The obtained results showed that the mechanical characteristics of this steel correspond to the standard values (Table 2).

Table 2

Mechanical properties of the steel 31CrMoV9

Characteristic	Tensile strength, MPa	Yield strength, MPa	Elongasion, %
The experimental sample	995	868	14.5
EN 10085:2001	900-1100	>700	>11

Thus, to obtain a uniform fine structure in 31CrMoV9 steel it is necessary to heat it to 850°C before quenching and normalizing heating which will also lead to resource savings.

Conclusions

During investigations was determined the effect of the increasing the austenitizing temperature on the change in the structure of the Cr-Mo-V steel.

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Received results allows to tentatively predict the final structure of the 31CrMoV9 steel after various heat treatment modes.

Determined, that the austenitizing temperature affects the cooling rate. To obtain broader results of this effect, it is necessary to conduct additional investigations of the kinetics of the transformations in the 31CrMoV9 steel during cooling from different temperatures. After heating 31CrMoV9 steel to different austenitization temperatures in the range of 850-1050°C and cooling under the same conditions, the steel structure changes.

After normalization, the structure of the 31CrMoV9 steel consisted of bainite and martensite, the amount of which increases with increasing temperature from 5-10% martensite at 850°C to 50% at 1050°C. The microhardness of the steel increases accordingly.

After heating to different temperatures, quenching and tempering, the structure of the 31CrMoV9 steel consists of tempered martensite different dispersity.

Established, that with an increase in the heating temperature, an increase in the prior austenite grain was observed, which led to the enlargement of martensite needles.

Determined, that with increasing heating temperature, the dispersion of pearlite depends on the size of austenitic grains.

To obtain a uniform fine structure for alloy steel is recommended the heated at a temperature of ~850°C before quenching or normalization.

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ВПЛИВ ТЕМПЕРАТУРИ ОБРОБКИ НА ФОРМУВАННЯ СТРУКТУРИ CR-MO-V СТАЛІ

Правильно підібрана термічна обробка, яка має на меті створення структури, що задовольняє вимогам виробника, є основним способом покращення якісних характеристик сталі. Досліджувану сталь 31CrMoV9 нагрівали до температур в діапазоні 850-1050°С і охолоджували у воді та на повітрі. Структура після нормалізації складалася з бейніту та мартенситу з різним співвідношенням. Підвищення температури нагріву призводить до збільшення кількості мартенситу з 5-10% при 850°С до 50% при 1050°С, що було показано дослідженнями. Мікротвердість сталі відповідно зростає. Структура сталі 31CrMoV9 складається із загартованого мартенситу, який характеризується різною морфологією після нагрівання до різних температур, гартування та відпуску. Середнє значення мікротвердості сталі зменшується зі збільшенням температури загартування. Зміна мікротвердості, ймовірно, пов'язана зі збільшенням об'єму залишкового аустеніту і розчиненням легованих карбідів.

Виявлено, що зі збільшенням температури нагріву збільшення початкового зерна аустеніту призводить до укрупнення голки мартенситу. Встановлено, що з підвищенням температури нагріву дисперсність перліту залежить від розміру аустенітних зерен. Підвищення температури аустенізації призводить до збільшення міжпластинної відстані. Для отримання однорідної структури леговану сталь слід нагрівати при температурі 850°С.

Ключові слова: легована сталь, температура нагріву, структура, розмір зерна, бейніт, мартенсит, термічна обробка, гартування, нормалізація

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