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Modern Trends in Heat Treatment of Chromium-Molybdenum Steel

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Abstract: This article discusses the heat treatment temperature regimes of chromium-molybdenum steel and their impact on the material's mechanical properties. The main heat treatment methods, including annealing, normalizing, quenching, and tempering processes, are analyzed. The influence of various processing regimes on the formation of the structure and the operational characteristics of the steel is studied. Optimal parameters that enhance strength, ductility, and wear resistance are identified. The obtained results enable the development of efficient heat treatment technologies that meet the requirements of various operating conditions.

Keywords: Heat treatment, chromium-molybdenum steel, modification, crystallization, phase transformations, mechanical properties, quenching, tempering, normalizing, annealing, thermokinetic diagrams, microstructure, grain size, residual stresses, strength, ductility, wear resistance, corrosion resistance, heat resistance, computer modeling, metallurgy, alloying, austenite, bainite, martensite.

Introduction: Relevance of studying the heat treatment process of chromium-molybdenum steel.

In the rapidly developing industrial economy of Uzbekistan, particularly in machine engineering, chromium-molybdenum steel is one of the most sought-after materials due to its properties:

- high strength;
- heat resistance;
- corrosion resistance.

Chromium-molybdenum steel is widely used in the energy and mechanical engineering sectors, where there are high demands on the reliability and durability of structures.

Heat treatment regimes play a crucial role in forming the mechanical properties of chromium-molybdenum steel, as they enhance the existing properties and characteristics of these steels. Consequently, the question of selecting optimal temperature regimes arises for domestic scientists and engineers, which would allow improving strength, ductility, wear resistance, and reducing internal stresses in the material.

Different heat treatment methods, such as annealing, normalizing, quenching, and tempering, have a varying impact on the steel's structure and properties.

In order to achieve optimal property values for chromium-molybdenum steels, especially to enhance their strength characteristics, the steel composition is alloyed with carbide-forming elements. Carbide-forming elements help stabilize the supercooled austenite [1] and improve the hardenability of the alloy.

Medium-carbon chromium-molybdenum steels have gained particular popularity in machine engineering, energy, and the mining and metallurgical industries due to their combination of high strength, toughness, wear resistance, and fatigue resistance. These properties make them indispensable for manufacturing critical components such as wheelbases for excavators, excavator buckets, inner linings of drum mills at beneficiation plants, gears, discs, turbine blades, and other structural elements subjected to significant mechanical and thermal loads.

It should be noted that the key factor determining the operational properties of steel is heat treatment, the parameters of which are selected based on special diagrams reflecting the kinetics of phase transformations. Most often, thermokinetic and isothermal diagrams are used for this purpose, which predict the metal's structure depending on temperature and holding time (Figure 1).

The kinetics of austenite decomposition, at high thermal values, is easily determined by the chemical composition of the steel, including iron, carbon, manganese, chromium, molybdenum, silicon, and other elements. Other factors, such as cooling rate, heating conditions, and preliminary treatment, are also critical.

The initial grain size of the metal significantly influences phase transformations, which, in turn, depends on the austenitization temperature and the regimes of preliminary heat treatment. Control of these parameters allows for the correction of the steel structure, achieving an optimal balance between strength, ductility, and resistance to failure [3].

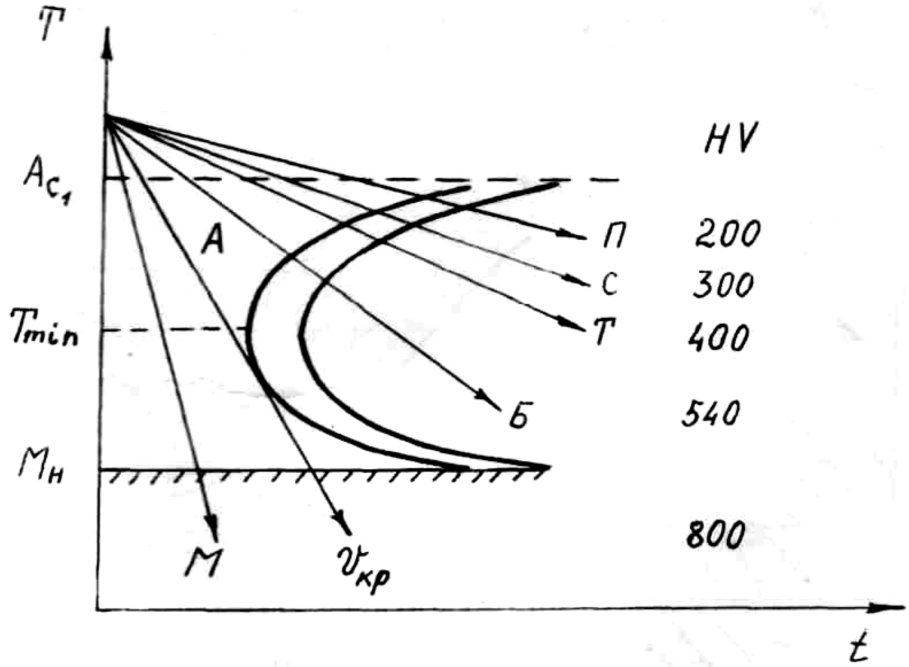

Figure 1. Isothermal transformation of austenite for chromium-molybdenum steel grade 35KhML.

Methodology of Heat Treatment Regimes for Chromium-Molybdenum Steel

When developing heat treatment regimes for chromium-molybdenum steel, the methodology of preliminary studies should take into account the impact of all main stages of production, as they directly affect the process of decomposing supercooled austenite and, consequently, the formation of the final structure of the billet after heat treatment [2].

The following types of heat treatment were considered during the study:

Annealing: Conducted within a temperature range of 850–900°C with slow cooling to relieve residual stresses and improve machinability.

Normalizing: The 35KhML grade chromium-molybdenum steel sample was heated to 870–920°C, followed by cooling in natural atmospheric conditions. This regime promotes the formation of a homogeneous structure and improves the material's mechanical characteristics.

Quenching: After heating to 850–900°C, the chromium-molybdenum steel was cooled in oil, ensuring a high level of strength and hardness.

Tempering: Performed at 500–700°C to reduce brittleness and increase toughness.

The equipment used included a muffle furnace with temperature control (Nabiterm), Brinell and Rockwell hardness testers, and an electron-optical metallographic microscope (OEM ODM).

When selecting the optimal heat treatment regime for chromium-molybdenum steels, several significant factors must be considered:

Casting crystallization after pouring, which depends on the billet's mass and production technology (use of molds, continuous casting, etc.). These parameters determine the size of the dendritic structure and the primary austenitic grain.

Heating and cooling processes during pressure treatment, which generally occur at temperatures above the phase transformation point. As a result, the primary dendritic structure is destroyed, and new austenitic grains are formed depending on the thermomechanical processing conditions.

Distribution and formation of austenitic grain and its decomposition products in the transverse cross-section of the billet during heating and cooling. These processes affect the material's structural homogeneity.

Moreover, several problems arise during thermomechanical processing of chromium-molybdenum steel. One of the most significant challenges is the inability to precisely assess the impact of the material's initial inhomogeneity on the thermokinetic diagram of supercooled austenite decomposition. This is due to uneven heating and cooling, as well as complex deformation distribution within the billet.

Even steels with identical chemical compositions can demonstrate significant differences in thermokinetic characteristics. The start time of supercooled austenite transformation can vary considerably, as its decomposition process involves a sequential transition from a pearlitic structure to bainitic and then martensitic structures. These changes result in a dramatic alteration of the material's mechanical properties.

The main reasons for such a range of values are related to:

Complex and uncontrolled thermomechanical history of the billet's structure formation at various stages of metallurgical production.

Differences in sample selection points, which are especially critical when working with large billets.

Given these features, it is clear that an individual approach to heat treatment is necessary. At present, it is impossible to apply standard quenching and tempering regimes for critical components based solely on the thermokinetic diagram obtained from trial bars or similar billets. Each billet requires the construction of an individual diagram with mandatory data verification to achieve the required operational characteristics of the material. For example, when cooling at a rate of 0.1–5 K/s for 35KhML chromium-molybdenum steel, the following structural changes can be observed, as shown in the diagram (Figure 2):

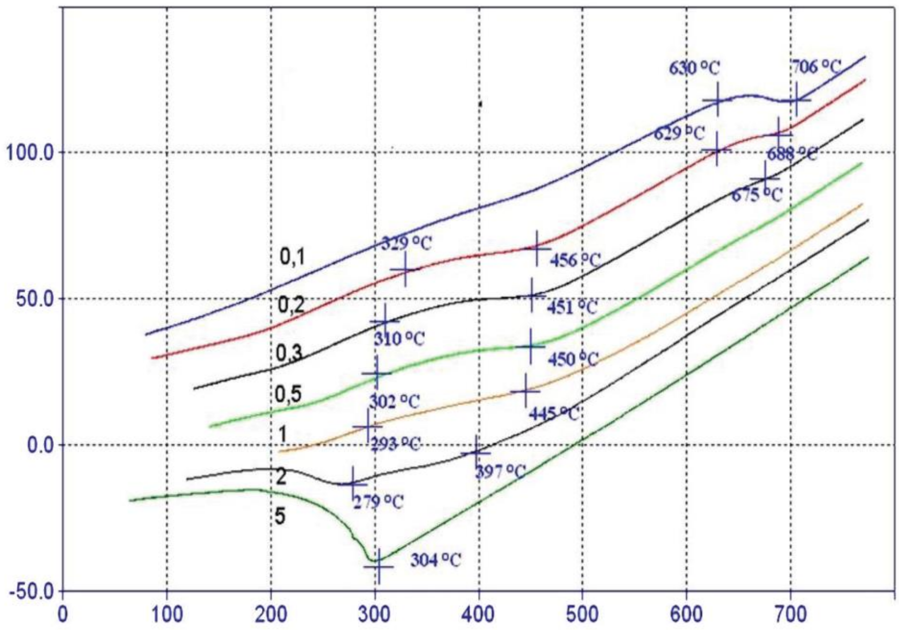

Figure 2. Structural changes during dilatometric investigation.

Table 1. Kinetics of supercooled austenite transformation in 35KhML steel.

Скорость охлаждения, К/с	Температура распада по 1-й ступени, °С		Температура распада по 2-й ступени, °С		Время начала распада, с	
	Начало	Окончание	Начало	Окончание	1-я ступень	2-я ступень
0,05	720–730	650	450	330	3000	8500
0,1	706–715	620–630	–	–	1800	4000
0,2	688–715	626–629	427–456	320–329	900	2000
0,3	–	–	368–451	279–310	600–800	1500
0,5	–	–	357–450	300–310	400–500	800
1,0	–	–	357–445	293–310	–	400
2,0	–	–	397	279	–	250 (min)
3,0	–	–	–	–	–	150 (min)

When developing heat treatment regimes for chromium-molybdenum steel, it is necessary to consider the probabilistic nature of the processes that transform the cast structure of the ingot, which occur under the influence of complex thermodynamic conditions and previous stages of thermomechanical processing. These changes are caused by thermal and deformation effects that:

contribute to stabilizing the chemical micro-heterogeneity of the alloyed steel in large billets;

form decomposition products of undercooled austenite, which depend on its heterogeneous composition at the level of the austenite grain.

Thus, the development of heat treatment regimes

requires a detailed consideration of all factors influencing the evolution of the material's structure, as well as the need to obtain data directly for each billet to ensure predictable mechanical properties and operational reliability of the chromium-molybdenum steel.

Key objectives and goals of heat treatment. Heat treatment of chromium-molybdenum steel pursues several key objectives:

Increasing strength and hardness

Heat treatment ensures the formation of a strong and wear-resistant structure, which is especially important for components operating under high loads. During quenching, a martensitic or bainitic structure is formed, and subsequent tempering allows for the optimal combination of strength and ductility.

Improving impact toughness and plasticity

To prevent brittle failure, it is important to achieve sufficient material toughness. Tempering at intermediate temperatures (350–500°C) helps relieve internal stresses and increases resistance to failure under dynamic loads.

Ensuring heat resistance and thermal stability

Chromium and molybdenum contribute to forming a structure that is resistant to high temperatures. Special aging and tempering regimes improve creep strength and property stability during prolonged operation under heat.

Improving corrosion resistance

With proper heat treatment, carbides are formed in the structure of chromium-molybdenum steel, which enhance resistance to oxidation and corrosion, especially in aggressive environments.

Minimizing residual stresses

After casting, mechanical processing, or welding, residual stresses remain in the metal, which can lead to deformations and cracking. Heat treatment, including normalizing and high-temperature tempering, reduces these stresses, improving the durability of the components.

CONCLUSION

Heat treatment of chromium-molybdenum steel is a key technological process that determines the operational characteristics of the material. The study has established that selecting optimal heat treatment regimes significantly improves the strength, ductility, heat resistance, and corrosion resistance of the steel, which is particularly important for products operating under high loads and in aggressive environments.

The results of the analysis of various heat treatment methods, including annealing, normalizing, quenching, and tempering, confirmed their significant impact on the steel's microstructure. Quenching forms a martensitic or bainitic structure, which increases strength and hardness, while tempering helps reduce residual stresses and increases toughness. Studies on the kinetics of phase transformations have shown that the chemical composition of the steel, cooling rate, and initial grain size play a decisive role in the formation of the final structure.

The need for an individual approach to developing heat treatment regimes was identified, especially for critical components, as the heterogeneity of the initial structure of the ingot can lead to significant variation in mechanical properties. To improve the accuracy of predicting phase transformations, the use of thermokinetic and isothermal diagrams is recommended, taking into account the chemical inhomogeneity and thermomechanical history of the blanks.

Thus, the proposed heat treatment technologies allow for the optimization of the properties of chromium-molybdenum steels for specific operating conditions, ensuring their reliability, durability, and high performance in mechanical engineering, energy, and the mining and metallurgical industries. A promising direction for further research is the application of modern computer modeling methods for predicting structural changes during heat treatment, as well as the development of new alloying compositions and processing regimes that contribute to improving the steel's characteristics.

REFERENCES

Sadovsky V.D., Popov A.A. "Diagrams of Kinetics of Transformation of Undercooled Austenite" // Metallography and Heat Treatment of Steel. Handbook. Vol. I / Edited by M.L. Bernstein, A.G. Rakhstadt. Moscow: State Scientific and Technical Publishing House for Ferrous and Non-Ferrous Metallurgy, 1961. Pp. 616–669.

Davenport E.S., Bain E.C. "Transformation of Austenite at Constant Subcritical Temperature" // Trans. AIME. 1930. Vol. 90. P. 117–154.

Harold W. Paxton. Commentary by: "Transformation of Austenite at Constant Subcritical Temperatures" // Metallurgical Transactions. 1970. Vol. 1. Iss. 12. P. 3479–3501.

Chernov D.K. "Selected Works on Metallurgy and Metallurgical Science" Moscow: Nauka, 1983. Pp. 9–48.

Tschernoff D.K. "A Critical Review of Articles by Lavrov and Kalakoutzky on Steel and Steel Ordnance, with Original Investigations on the Same Topic" // Proceedings of the Institution of Mechanical Engineers. June 1880. Vol. 31. No. 1. Pp. 286–307.

Chernov D.K. "Selected Works on Metallurgy and Metallurgical Science" Moscow: Nauka, 1983. Pp. 70–99.

Gorynin I.V. "Reflections with Optimism" St. Petersburg: Polytechnical University Publishing House, 2014. 526 p.

Dyachenko S.S. "Formation of Austenite in Iron-Carbon Alloys" Moscow: Metallurgiya, 1982. 128 p.