FEATURES OF CHOOSING TEMPERATURE REGIMES FOR CHROMIUM-MOLYBDENUM STEEL FOR SUBSEQUENT HEAT TREATMENT

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Research on the heat treatment of various alloys requires the selection of more favorable thermal regimes, as the choice significantly affects the thermomechanical properties of the alloys. We present the development of a technology to improve the strength and wear resistance characteristics of chromium-molybdenum steels through the optimization of heat treatment regimes. Experimental studies confirmed that short-term intensive heating followed by rapid cooling leads to a significant improvement in the operational properties of the alloys. These processes result in increased hardness, wear resistance, and fatigue strength, which is particularly important for components working under high loads and abrasive wear conditions.

A comprehensive analysis of the influence of thermal-time parameters of heat treatment on the formation of the microstructure and mechanical properties of carbon chromium-molybdenum steels was conducted. The optimal heating and cooling regimes were determined, contributing to the formation of a fine-grained structure with a uniform distribution of carbide inclusions, which positively affects the strength characteristics of the material. Additionally, the influence of various heat treatment methods, including hardening, tempering, and thermomechanical processing, on the final properties of the steels was considered.

Furthermore, the technology of die casting was studied, ensuring the production of parts with high precision, minimal tolerances, and excellent reproducibility of geometry. Special attention was given to the features of mold formation of cast billets, as well as the influence of casting conditions on defects, density, and homogeneity of the material's structure. The application of this technology, combined with optimal heat treatment regimes, significantly enhances the operational characteristics of the finished products, making it highly relevant in the mass production of critical parts and structures.

The mining and metallurgy industry of Uzbekistan demonstrates steady growth, which requires the implementation of innovative solutions in metal production and processing. Chromium-molybdenum alloys play a key role in the manufacturing of mining equipment components, including wheelbases, buckets, and the inner liners of ball mills. These alloys have outstanding mechanical properties such as high hardness, wear resistance, and the ability to withstand significant operational loads. Their demand is also driven by their corrosion resistance and the ability to maintain their properties at high temperatures.

Contemporary research focuses on the development of alloys with improved chemical compositions, enhanced plasticity, and optimized heat treatment parameters. Special attention is given to secondary raw materials and recycling methods, which help reduce production costs and minimize environmental impact. The optimization of temperature regimes during the austenitic phase and the refinement of chromium and molybdenum alloying techniques contribute to the increased strength and durability of the finished products.

Active research is underway to improve casting and subsequent mechanical processing technologies aimed at minimizing internal defects and enhancing the homogeneity of the material's structure. Additionally, methods for introducing nanodisperse modifiers are being studied, which allow for increased strength, improved corrosion resistance, and reduced risk of component failure under variable loads. Modern technologies make it possible to increase the material's density, reduce residual stresses, and extend the service life of the products.

Effective heat treatment and surface hardening regimes have been developed to achieve high strength and wear resistance for chromium-molybdenum steels. Induction heating (RF) and oxy-fuel treatments allow for the hardening of massive components, such as the drive wheels of mining excavators, extending their service life. Additionally, laser hardening enables local alteration of surface properties without affecting the internal structure of the product, significantly expanding the range of applications for these technologies.

Experimental studies have shown that short-term, intense heating followed by rapid cooling significantly improves the operational characteristics of alloys. The variety of cooling media (air, oil, salt baths) allows for the adaptation of the process to the specific requirements of various industries. The implementation of new tempering regimes helps reduce residual stresses, which directly affects the service life of components. Control of the cooling rate and regulation of the phase composition allow for the optimization of the balance between hardness and impact toughness.

Methods such as nitriding and carbo-nitriding are also being studied, which improve wear resistance and resistance to corrosion cracking. Combined processing schemes are being developed, which include sequential stages of quenching, tempering, and surface hardening. This approach significantly enhances the operational characteristics of the products. A crucial aspect is the analysis of the influence of thermal regimes on the distribution of residual stresses, as uniform cooling plays a critical role in forming the strength properties of alloys.

Modern manufacturing processes actively utilize additive technologies and metal injection molding (MIM), which is especially relevant for producing components with complex geometries. The injection molding method, based on the use of metal powders and polymer binders, allows for high precision and minimizes structural defects. Modern pressing and sintering methods contribute to further improvement of alloy characteristics, reducing porosity and increasing the strength of the products.

The development of new binder components and sintering technologies significantly reduces internal defects and ensures the homogeneity of the material's structure. The use of innovative density control methods ensures compliance with industrial product requirements. Injection molding allows for the production of components with high precision and reproducibility, which is particularly important for mass production. Work is being done on the creation of composite powders with nanodisperse carbides, which significantly improves the mechanical properties of components.

Additionally, the possibility of using multilayer powder structures is being studied, providing a gradient change in mechanical properties depending on working conditions. Various types of binder materials are being analyzed for their impact on shrinkage during sintering. New post-processing methods, such as laser hardening and chemical etching, are also being developed to improve the durability of components and their resistance to external influences.

Chromium-molybdenum steel 38XML is one of the most promising alloys for use in MIM technology. It is characterized by high strength, thermal load resistance, and corrosion resistance. Chemical composition analysis of sintered parts confirmed compliance with GOST 4543 and international standards. Impact toughness and corrosion resistance tests showed a high level of operational reliability of the material.

Widely used since the 1950s for the production of ceramic products, the low-pressure hot casting technology [2] evolved in the 1990s into high-pressure casting technologies for not only ceramics but also metals.

The injection molding technology is based on the use of a specially prepared mixture of powders and polymer binder, called feedstock, followed by molding the product by injecting this mixture into a casting mold cavity and curing the casting under excessive external pressure, extracting the cured casting, removing the polymer binder, and then sintering the porous powder part, resulting in a "finished" part. After sintering, the part is subjected to finishing mechanical processing, as well as heat treatment (HT) and chemical-thermal treatment (CTT) to ensure the required strength, impact toughness, and wear resistance.

Despite more than thirty years of successful application and development of this technology abroad [3], its practical implementation in Uzbekistan began less than ten years ago. Data on the scientific and theoretical foundations of the technology are publicly available [3], but information of a private and applied nature (material characteristics and compositions, technological regimes) is limited.

Research results and discussion. The sintered, non-heat-treated steel 38XMJI obtained by the MIM method has a relatively coarse-grained ferrite-pearlite microstructure, which is typical for hypoeutectoid steels. In this structure, a close ratio of ferrite to pearlite is observed, with the pearlite fraction being slightly higher (≈55%).

Ferrite is located as a thick network along the boundaries of pearlite grains, which is characteristic of a normalized structure. Depending on the temperature, sintering time, and cooling rate, a bainitic structure may also form in the studied steel [7].

Table 1. Chemical Composition, % by weight, of steel obtained by the MIM method and its comparison with the allowances of Russian and foreign standards for the composition of steel 38ХМЛ and its analogs

Steel 38ХМЛ and its analogs	C	Si	Mn	Ni	Cr	Mo	Fe
Sintered Analog of Steel 38ХМЛ, Produced by MIM Method from Foreign Raw Materials	(0,4102 ± 0,0045)	0,321 ± 0,012	1,015 ± 0,057	0,031 ± 0,009	1,128 ± 0,017	0,227 ± 0,015	96,54 ± 0,057
Steel 38ХМЛ (GOST 4543-71)	0,35...0,42	0,17...0,37	0,35...0,65	До 0,03	0,90...1,30	0,20...0,30	Others
MIM-4140 [11] (MPIF standard 35)	0,30...0,50	up to 0,60	up to 1,00	-	0,80...1,20	0,20...0,30	
AISI 4140 (UNS G414000)	0,38...0,43	0,15...0,3	0 0,75...1,0	up to 0,05	0,80...1,10	0,15...0,25	

Rational heat treatment and chemical-thermal modification of steel 38KhML ensure high mechanical properties and durability of parts. The use of MIM technologies in combination with traditional metalworking methods opens new prospects for industrial production.

It has been shown that the selection of rational thermal and chemical-thermal treatment regimes for 38KhML steel parts obtained through MIM technology can provide high strength properties in the serial production of small-sized parts with complex geometric configurations typical of MIM components, along with high surface quality and dimensional accuracy.

It has been established that the chemical composition of sintered MIM parts is consistently within the tolerances set by domestic and international standards for 38KhML steel and its foreign analogs.

The medium-carbon chromium-molybdenum steel obtained by the MIM method, after quenching in oil and subsequent tempering at various temperatures, has a hardness that is comparable to that of high-quality construction steel 38KhML according to GOST 4543.

Nitriding of parts made from sintered 38KhML steel for 8 hours results in the formation of a hard nitride phase layer on the surface, approximately 20 µm thick, which provides high wear resistance for nitrided MIM products.

The development of hardening methods, optimization of heat treatment regimes, and the implementation of nanotechnologies enable the creation of wear-resistant and durable components for Uzbekistan's mining and metallurgical industry, ensuring its further development.

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