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Technologies for Improving the Mechanical Properties of Gray Cast Iron

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Annotation
Gray cast iron remains one of the most commonly used engineering materials because of its excellent casting properties, low cost, and ease of machining. At the same time, its relatively weak tensile strength, limited toughness, and moderate wear resistance restrict its wider use in demanding structural applications. For this reason, improving the mechanical performance of gray cast iron continues to attract considerable interest among researchers and engineers. This paper reviews the main approaches that contribute to enhancing its properties, such as alloying with selected elements, modification of graphite morphology techniques. Particular emphasis is placed on how alloying additions and microstructural changes influence strength and durability. The discussion highlights that combining these methods offers a practical pathway to extend the reliability and service life of gray cast iron in modern industry.

Keywords: Gray cast iron, mechanical properties, fluidity improvement, thin-walled castings, in-furnace treatment, out-of-furnace modification, copper phosphide (CuP_2), molybdenum (Mo), microstructure, corrosion resistance.

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Introduction. One of the pressing challenges in modern industry is the production of high-quality yet cost-effective thin-walled cast products. This goal is closely tied to enhancing the strength, durability, and overall performance of components manufactured by casting, which are widely used in engineering and industrial applications. At the same time, growing attention is being paid to reducing fuel and energy consumption, which has created a strong demand for lightweight but durable materials.

Gray cast iron alloys play an important role in meeting this demand. By optimizing alloy composition or decreasing wall thickness without compromising strength, components cast for the automotive sector can lower production costs per vehicle by nearly 15% compared with steel or aluminum alternatives. The global need for thin-walled castings has therefore stimulated the development of numerous methods and technologies aimed at producing reliable, inexpensive, and competitive parts. Notably, in 2021 gray cast iron held the largest share in the global steel and cast-iron market, accounting for about 37% of total production [1].

The demand for cast iron alloys in the automotive sector continues to rise, largely due to their affordability and suitability for large-scale production. Countries such as the United States, China, Germany, India, Australia, the United Kingdom, Turkey, and Brazil are among the leading producers of cast iron alloys. In 2021, member states of the European Foundry Association reported a total output of approximately 10.7 million tons of cast iron and steel alloys, representing a 17.6% increase compared to the previous year. Within this figure, gray cast iron accounted for 49.3% of total production, highlighting the material's strong demand and wide application [2].

Research carried out by leading international scientists has demonstrated that modifying the chemical composition of gray cast iron and advancing casting technologies make it possible to produce thin-walled, high-strength components that are both cost-effective and durable. In industries such as mining, metallurgy, and engineering, gray cast iron is commonly employed for casting components. The addition of modifiers, together with control over cooling rates, significantly improves properties such as corrosion resistance, hardness, fluidity, and overall performance [3].

Materials and Methods. The object of this study is gray cast iron alloys of grade G24 (GOST 1412–85) and lift-gate components employed in metallurgical enterprises. The research specifically focuses on the production technology of lifting roof details manufactured in sand–clay molds.

Within the scope of the investigation, the chemical composition of the samples was determined using an emission spectrometer, while high-speed metallurgical microscopes and scanning electron microscopes were applied to examine the alloy's microstructure and to analyze the elemental distribution maps. In addition, standard methods were used to measure the hardness of the samples.

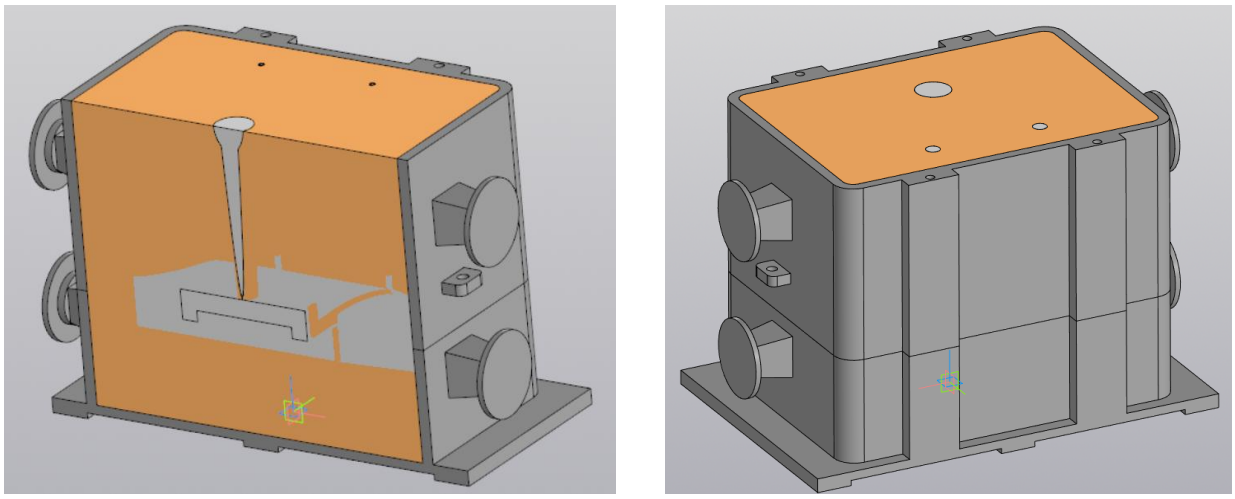
The lifting roof component operates in the cooling lines of metallurgical plants. These parts are thin-walled, high-strength castings, commonly produced by pressure mold casting. This is largely due to the complexity of preparing models and designing appropriate alloy compositions. At present, one of the major issues faced by "Uzmetkombinat" JSC is the disruption of continuous production, caused by logistical constraints during the pandemic and the long delivery times of such parts from countries like Belarus and China.

Given this situation, the development of casting technology for these details in the conditions of "Uzmetkombinat" JSC using sand–clay molds has become an urgent necessity. As part of the research, several technological approaches were designed and implemented. Furthermore, by improving processing techniques for gray cast iron both inside and outside the furnace, significant enhancements were achieved in terms of fluidity, hardness, and corrosion resistance of the alloy [4-7].

To enhance both the castability and mechanical properties of gray cast iron, modifiers were introduced to promote the formation of additional graphite crystallization centers. For the production of the lifting roof component, ferromolybdenum (FeMo70) was added into the furnace, while copper phosphite (CuP_2) was introduced during further processing to improve fluidity and hardness. According to GOST 4515–93, copper phosphite may contain up to 10% phosphorus. Although phosphorus is generally considered a detrimental element in cast iron, in controlled amounts it contributes to higher hardness and improved corrosion resistance.

During the experiments, 45 kg of secondary cast iron was used for a single lifting roof part. Taking into account the addition of 0.225 kg of CuP_2 to this batch, the phosphorus content was calculated to be approximately 0.05%, even when considering the maximum phosphorus concentration of 10% in the modifier. Thus, the phosphorus level remained within the permissible

limits established by GOST 1412–85 for gray cast iron alloys, ensuring compliance with standard requirements (Fig. 1).



a) b)

Figure 1: A* figure *of the placement of the mold of the lifting roof detail a) a cropped image of the placement of the models in the mold b) flasks layout of models

An increase in the concentration of carbon (C), silicon (Si), and phosphorus (P) within certain limits contributes to improved fluidity of cast iron. However, when the sulfur (S) content exceeds 0.15%, it negatively affects fluidity. Phosphorus has little influence on the graphitization process, but it plays a significant role in enhancing the casting fluidity. In gray cast iron, phosphorus promotes the formation of a ternary eutectic that melts relatively easily at around 950 °C. During solidification, this eutectic consists of phosphorus-enriched austenite, cementite (Fe_3C), and iron phosphide (Fe_3P) [8-14].

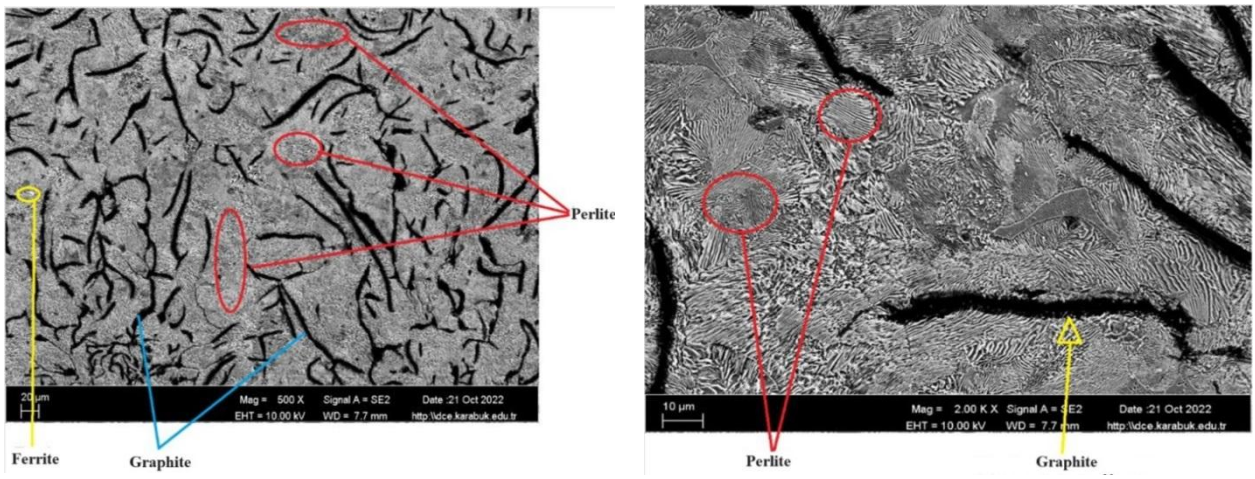
The enhanced fluidity observed in phosphorus-containing cast irons is primarily attributed to this ternary eutectic, which readily becomes mobile in the liquid state. Furthermore, the formation of iron phosphide phases within the alloy improves both the hardness and corrosion resistance of gray cast iron.

Results and Discussion. In this study, molybdenum was chosen as a modifier for G24 gray cast iron, and its influence on mechanical properties was systematically evaluated. The addition of copper phosphide was found to enhance both the hardness and fluidity of the alloy, while molybdenum was introduced into the furnace in amounts ranging from 0.1% to 0.6% to further improve mechanical performance. Among the tested samples, a copper phosphide concentration of 0.5% proved to be optimal, as it ensured sufficient fluidity of the molten alloy without increasing brittleness or causing defects during machining of the components.

Based on the requirements of GOST 4759–91, ferromolybdenum (FeMo70) was added into the melt at a temperature of 1430–1440 °C. Molybdenum plays a key role in carbide formation and strengthens gray cast iron by promoting the transformation of austenite from fine pearlite into bainite, thereby enhancing both hardness and strength. Moreover, the molybdenum–carbon interaction introduced through modification slows the precipitation of free graphite, increases its amount in a controlled manner, improves corrosion resistance, and maintains satisfactory machinability of the cast details [15-19].

The microstructure and elemental distribution of the samples were analyzed using a Carl Zeiss Ultra Plus Field Emission Scanning Electron Microscope in the laboratories of the Iron and Steel Institute at Karabuk University. For each specimen, two sections were examined under magnifications of ×100, ×500, ×1000, ×1500, and ×2000. The SEM observations were carried out

at a working distance of 7.6–7.7 mm with an accelerating voltage of 10.00 kV, employing the SE2 detector. Representative microstructural images obtained under these conditions are shown in Figure 2.



a) b)

Figure 2: Microstructures of copper phosphide 0.5% and molybdenum 0.3% in Carl Zeiss Ultra Plus Field Emission scanning electron microscope in the laboratory of "Iron and Steel" Institute of Karabuk University a) image magnified x500 times b) image magnified x2000.

The separation of graphite from carbon plays a crucial role in the liquefaction of cast iron, particularly in the manufacture of thin-walled components. Experimental observations revealed that the ductility, tensile strength, and hardness of gray cast iron improve under these conditions. However, when copper phosphide (CuP_2) is introduced at concentrations of 0.8% or higher, although enhancements in fluidity and hardness were recorded, the material exhibited an increased tendency toward brittleness [20-25].

Conclusions. The study demonstrates that several technological approaches can significantly enhance the quality and performance of thin-walled gray cast iron castings:

1. The development of an out-of-furnace treatment method for liquid alloy makes it possible to improve the fluidity of molten gray cast iron by approximately 9–11%, thereby facilitating the production of high-quality thin-walled castings.
2. The implementation of an in-furnace treatment technology has been shown to increase the hardness of cast products by about 10–12%, contributing to enhanced mechanical performance.
3. The research findings suggest that modification of gray cast iron with CuP_2 and Mo elements in the liquefaction furnace not only improves casting efficiency but also reduces the overall consumption of modifiers, making the process more cost-effective.
4. A casting mold placement scheme for the lifting roof detail has been developed, ensuring uniform distribution of corrosion resistance across the strengthened surface. This provides a practical guideline for selecting more effective mold materials.
5. The study confirms that increasing the fluidity of gray cast iron enables the production of thin-walled and geometrically complex components, expanding the potential applications of gray cast iron in advanced engineering.

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