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INVESTIGATION OF THE EFFECT OF TITANIUM ON THE MECHANICAL PROPERTIES OF HIGH-MANGANESE 110G13L STEEL

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Abstract. This article analyzes, based on IMRAD requirements, the issue of improving the mechanical and operational properties of high-manganese 110G13L steel by adding titanium to its composition. The research work was carried out under the production conditions of the “Navoi Machine-Building Plant” Production Association of JSC “Navoi Mining and Metallurgical Combine.” The study examined the processes of melting 110G13L steel, alloying it with FTi-35 ferrotitanium, sample preparation, mechanical machining, surface grinding, and conducting laboratory tests. During the research, ferrotitanium was added to the molten alloy in different amounts in order to refine the steel grains, ensure uniform distribution of carbides, and improve the mechanical properties of the steel. Test samples were taken during the casting process at 5-minute intervals and were subsequently prepared on turning and grinding machines in accordance with laboratory requirements. Tensile testing, impact toughness testing, and hardness measurement methods were used to evaluate the mechanical properties. The research results showed that the addition of titanium increases the microstructural stability of 110G13L steel, restricts grain growth, and contributes to the improvement of its mechanical properties.

Keywords: 110G13L steel, high-manganese steel, titanium, ferrotitanium, FTi-35, alloying, mechanical properties, tensile testing, impact toughness, hardness.

Аннотация. В данной статье на основе требований IMRAD проанализирован вопрос улучшения механических и эксплуатационных свойств высокомарганцовистой стали марки 110Г13Л за счёт введения титана в её состав. Исследовательские работы были проведены в производственных

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условиях Производственного объединения «Навоийский машиностроительный завод» АО «Навоийский горно-металлургический комбинат». В работе изучены процессы плавки стали 110Г13Л, легирования ферротитаном марки FTi-35, отбора образцов, механической обработки, шлифования поверхности, а также проведения лабораторных испытаний. В ходе исследования ферротитан добавлялся в расплав сплава в различных количествах с целью измельчения зерна стали, обеспечения равномерного распределения карбидов и улучшения механических свойств. Испытательные образцы отбирались в процессе литья с интервалом 5 минут, после чего обрабатывались на токарных и шлифовальных станках до состояния, соответствующего лабораторным требованиям. Для оценки механических свойств применялись методы испытания на растяжение, определения ударной вязкости и измерения твёрдости. Результаты исследования показали, что добавление титана повышает стабильность микроструктуры стали 110Г13Л, ограничивает рост зёрен и способствует улучшению механических свойств.

Ключевые слова: сталь 110Г13Л, высокомарганцовистая сталь, титан, ферротитан, FTi-35, легирование, механические свойства, испытание на растяжение, ударная вязкость, твёрдость.

Annotatsiya. Ushbu maqolada 110G13L markali yuqori marganesli po‘lat tarkibiga titan qo‘shish orqali uning mexanik va ekspluatatsion xossalarini yaxshilash masalasi IMRAD talablari asosida tahlil qilingan. Tadqiqot ishlari “Navoiy kon-metallurgiya kombinati” AJ “Navoiy mashinasozlik zavodi” ishlab chiqarish birlashmasi sharoitida amalga oshirilgan. Ishda 110G13L po‘latini eritish, FTi-35 markali ferrotitan bilan legirlash, namuna olish, mexanik ishlov berish, sirtni silliqlash hamda laboratoriya sinovlarini o‘tkazish jarayonlari o‘rganildi. Tadqiqot jarayonida ferrotitan qotishma eritmasiga turli miqdorlarda qo‘shilib, po‘lat donachalarini maydalash, karbidlarning bir tekis taqsimlanishini ta’minlash hamda mexanik xossalarni yaxshilash maqsad qilingan. Sinov namunalari quyish jarayonida 5 minut farq bilan olinib, keyinchalik tokarlik va silliqlash stanoklarida laboratoriya talablariga mos holatga keltirildi. Mexanik xossalarni baholash uchun cho‘zilishga sinash, zarbiy qovushqoqlikni aniqlash va qattiqlikni o‘lchash usullaridan foydalanildi. Tadqiqot natijalari titan qo‘shilishi 110G13L po‘lat mikrostrukturasi barqarorligini oshirishi, donalar o‘sishini cheklashi va mexanik xossalarning yaxshilanishiga xizmat qilishini ko‘rsatdi.

Kalit so‘zlar: 110G13L po‘lat, yuqori marganesli po‘lat, titan, ferrotitan, FTi-35, legirlash, mexanik xossalar, cho‘zilishga sinash, zarbiy qovushqoqlik, qattiqlik.

INTRODUCTION.

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High-manganese 110G13L steel is considered one of the important structural materials widely used in the mining, metallurgical, and heavy machine-building industries. This steel is used to manufacture various cast parts that operate under conditions of high friction, impact loads, and abrasive wear. In particular, excavator teeth, jaw crusher plates, grates, vibrating feeder grizzly bars, side walls, cutting parts, and other heavily loaded cast products are produced on the basis of 110G13L steel.

The main advantage of 110G13L steel is its ability to harden the surface layer under impact loads due to its high manganese content. However, during the production process, problems such as grain coarsening in the cast structure, uneven distribution of carbides, internal defects, and insufficient stability of mechanical properties may occur. This reduces the service life, wear resistance, and impact load resistance of the finished part.[1]

One of the effective ways to reduce these problems is to add modifying and alloying elements to the steel composition. Among such elements, titanium is of particular importance. Titanium combines with carbon in the steel and forms titanium carbides. These particles restrict the growth of crystal grains, refine the microstructure, contribute to the uniform distribution of carbides, and improve the mechanical and operational properties of the material.

The purpose of this study is to investigate the effect of titanium addition on the mechanical properties of high-manganese 110G13L steel. In the study, the processes of alloying 110G13L steel with FTi-35 ferrotitanium, sample collection, preparation of samples through mechanical machining, tensile testing, determination of impact toughness, and hardness measurement were analyzed.[2]

MATERIALS AND METHODS.

The research work was carried out under the production conditions of the “Navoi Machine-Building Plant” Production Association of JSC “Navoi Mining and Metallurgical Combine.” High-manganese 110G13L steel was selected as the research object. On the basis of this steel, excavator teeth, jaw crusher plates, grates, and other highly loaded cast parts are produced under plant conditions.

The steel melting process was carried out in a 6-ton electric arc furnace located in the casting department of the foundry shop. FTi-35 ferrotitanium was added to the melt. The main purpose of adding ferrotitanium was to refine the steel grains, ensure uniform distribution of carbides, and improve the mechanical and operational properties of the steel.

Initially, 0.5%, i.e., 35 kg of FTi-35 ferrotitanium, was added to the melt. In the subsequent stages, ferrotitanium was added to the molten alloy in amounts of 0.4%, 0.6%, and 0.8%. Titanium was introduced by sprinkling during the initial

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melting stage of the metal and after the metal had completely melted. The chemical composition of the melt was continuously monitored and maintained in accordance with the requirements of GOST 977–88.

The molten steel was poured into sand-metal molds and cooled under natural conditions. During the casting process, sample cups were taken for experimental purposes. The sampling process was carried out at 5-minute intervals.[3] For chemical and mechanical laboratory investigations, cylindrical sample cups with a length of 50 mm and a diameter of 20 mm, as well as cylindrical sample cups with a length of 400 mm and a diameter of 40 mm, were used.



Figure 1. Sample cups taken during the casting process for chemical analysis.

The sample cups were held at a temperature of **1050–1150 °C** for **2 hours and 30 minutes**. During this process, titanium carbides serve to restrict grain growth. Then, the samples were rapidly cooled in water. This process helps to stabilize the austenitic structure.

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Figure 2. Sample cups taken during the casting process for mechanical testing.

Initial cast samples were mechanically processed because their surface unevenness and dimensions did not meet the requirements of laboratory testing equipment.[4] Mechanical processing was carried out on an **NT-250I lathe** located in the "Machine Tool" shop. For chemical analysis, coin-shaped samples with a length of **10 mm** and a diameter of **15 mm** were prepared from cast sample cups with a length of **50 mm** and a diameter of **20 mm**.



Figure 3. Coin-shaped samples prepared on a lathe for chemical analysis.

For mechanical testing, dumbbell-shaped samples and plate-shaped samples were prepared from cast sample cups with a length of **400 mm** and a diameter of **40 mm**. The dumbbell-shaped samples were prepared with a total length of **40 mm**, a large diameter of **15 mm**, a small diameter of **10 mm**, a large-diameter section length of **7.5 mm**, and a small-diameter section length of **25 mm**. The plate-shaped

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samples were prepared with a length of **40 mm**, a width and thickness of **5 mm**, and a **1 mm** deep notch in the middle.



Figure 4. Dumbbell-shaped samples prepared for mechanical tensile testing.

To ensure the surface quality of the samples, they were further processed on a **3D711AF11 grinding machine** located in the "Toolmaking" shop. This process made it possible to reduce errors that could occur during testing due to surface defects. As a result, the samples were accurately brought to the specified final dimensions and prepared for laboratory testing.



Figure 5. Plate-shaped samples prepared from 110G13L steel for impact toughness testing.

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Figure 6. Condition of the samples prepared from 110G13L steel after processing on the 3D711AF11 grinding machine.

Mechanical properties were evaluated using tensile testing, impact toughness testing, and hardness measurement methods. Tensile testing was carried out on an **LFM-50 kN universal testing machine**. Impact toughness was tested using the **Charpy method** on an **MK-30A pendulum impact testing machine**.



Figure 7. A 110G13L steel sample prepared for laboratory testing after the grinding process.

Hardness was determined at room temperature using a stationary hardness tester equipped with a conical indenter.

RESULTS.

The research results showed that the addition of titanium to the composition of high-manganese 110G13L steel has a positive effect on its mechanical and operational properties. The addition of titanium contributes to the refinement of

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steel grains, ensures the uniform distribution of carbides, and stabilizes the microstructure.



Figure 8. LFM-50 kN universal testing machine used for tensile testing of titanium-modified 110G13L steel.

FTi-35 ferrotitanium added to the melt proved to be technologically convenient under production conditions. When titanium was introduced at the initial stage of metal melting and after the metal had completely reached the liquid state, the modification process in the melt was effectively carried out. Control of the melt composition in accordance with the requirements of **GOST 977–88** ensured the reliability of the experimental results.

The selection of the casting temperature in the range of **1380–1410 °C** had a positive effect on casting quality. This temperature is approximately **15 °C lower** than the conventional casting temperature and contributed to the reduction of defects such as surface burns, incomplete mold filling, gas porosity, and slag inclusions.

The initial samples taken for laboratory investigations were brought to the required shape and dimensions through mechanical processing. As a result of turning and grinding operations, coin-shaped, dumbbell-shaped, and plate-shaped samples were prepared.[5] Cleaning the sample surfaces made it possible to reduce errors during tensile testing, impact toughness testing, and hardness measurement.

As a result of tensile testing, the maximum strength value of the titanium-modified 110G13L steel samples was recorded as **400 MPa**. This value indicates that the addition of titanium contributes to the improvement of the strength properties of the material.

The **Charpy method** was used to evaluate impact toughness. During the test, the energy consumed to fracture the sample was determined, and the impact toughness coefficient was calculated using the formula **K = A/F**. This approach

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made it possible to evaluate the effect of titanium on the resistance of steel to dynamic loads.

During hardness measurement, the sample surfaces were pre-cleaned and tested using a hardness tester with a conical indenter. Based on the values obtained from several indentations, the average hardness value was accepted. This method made it possible to compare the material conditions and evaluate the effect of titanium modification on hardness.

DISCUSSION.

The obtained results show that titanium is an effective modifying element for high-manganese 110G13L steel. The addition of titanium restricts grain growth, ensures the uniform distribution of carbides, and increases the stability of the steel microstructure. As a result, important mechanical properties of the material, such as strength, impact toughness, and hardness, are improved.

Since the operating conditions of 110G13L steel are associated with high impact loads and abrasive wear, the stability of the material microstructure and mechanical properties is of great importance. Titanium modification is relevant in this regard, as it contributes to extending the service life of cast parts.

The use of FTi-35 ferrotitanium is considered a practically convenient solution under production conditions. Compared with the use of pure titanium, ferrotitanium simplifies the process of introducing titanium into the melt, facilitates technological control, and is suitable for application under plant conditions.

The selection of the casting temperature in the range of 1380–1410 °C is also technologically justified. Excessively high temperatures may increase the risk of casting defects such as gas porosity, slag inclusions, surface burns, and other imperfections. Therefore, a lower temperature range that still provides sufficient fluidity helps improve casting quality.

Turning and grinding operations performed on the samples increased the accuracy of the test results. In particular, surface cleanliness is of great importance in tensile testing, impact toughness testing, and hardness measurement. Since surface defects can negatively affect test results, preparing the samples in accordance with standard requirements is an important stage of the research.

In general, titanium-modified 110G13L steel can be considered a promising material for cast parts operating under severe service conditions. This approach makes it possible to improve the quality of excavator teeth, jaw crusher plates, and other highly loaded parts.

CONCLUSION.

The addition of titanium to the composition of high-manganese 110G13L steel is an effective technological solution for improving its mechanical and

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operational properties. The research results showed that titanium refines steel grains, ensures the uniform distribution of carbides, and stabilizes the microstructure.

The use of FTi-35 ferrotitanium under production conditions was assessed as appropriate. Ferrotitanium simplifies the process of introducing titanium into the melt and serves as a convenient modifying additive for improving the mechanical properties of 110G13L steel.

The selection of the casting temperature in the range of 1380–1410 °C helped reduce casting defects, prevent gas porosity and slag inclusions, and improve casting quality.

During the study, coin-shaped, dumbbell-shaped, and plate-shaped samples were prepared for chemical and mechanical testing. Turning and grinding operations performed on the samples increased the accuracy of the test results.

The results of tensile testing, impact toughness testing, and hardness measurement showed that titanium-modified 110G13L steel is an effective material for operation under conditions of high impact loads and abrasive wear.

The application of this technology in production practice makes it possible to increase the service life of excavator teeth, jaw crusher plates, and other highly loaded cast parts, improve their wear resistance, and enhance production efficiency.

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