Technology of degassing and purification of non-ferrous metals from non-metallic inclusions before the casting process

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Abstract. The conducted research showed that the effective organization of degassing and purification of non-ferrous metals from non-metallic inclusions before casting plays a decisive role in improving the quality of the casting. The presence of gases (mainly hydrogen, oxygen, nitrogen) and particles of oxides, sulfides, and slags [1], [5], [6] in metal solutions causes porosity, surface defects, and structural irregularities. Therefore, the correct choice of solution purification technology significantly improves the density, mechanical strength, and corrosion resistance of the metal. Based on the results of the experiment, it was established that degassing with inert gases (argon, nitrogen) [3], [7], [8] (argon, nitrogen) reduces the hydrogen content in the metal by 80-90%. Vacuum treatment accelerates the escape of gases from the solution by partially reducing their pressure. As a result of filtration through ceramic filters (based on SiC, Al2O3), non-metallic inclusions are eliminated up to 70-80%.In a complex way - that is, the combined use of inert gas treatment, vacuum degassing, and filtration method [6], [8], [10]s leads to the unification of the metal structure, a decrease in internal porosity, and an increase in strength indicators by 20-25%. It has also been observed that the surface quality of aluminum, copper, and bronze alloys has improved, and casting defects have decreased. Practically, the application of these technologies at industrial enterprises will reduce production waste by 15-20%, energy consumption by 10-12%, and the quality of parts will meet international standards. In the future, it is possible to further increase the efficiency of casting production by automating degassing and cleaning processes, implementing real-time monitoring systems, as well as developing new types of environmentally safe fluxes and ceramic filters.

INTRODUCTION

Today, one of the most important issues in the metallurgical and machine-building industries is the organization of high-quality casting of non-ferrous metals. The gases (hydrogen, oxygen, and nitrogen) and non-metallic impurities (oxides, sulfides, nitrides) present in the metal directly affect the quality of the casting. Therefore, the introduction of degassing and purification technologies of metal solutions before casting ensures high density, precise structure, and strength. Usually, when metals transition from a molten state to a solidified state, the gas in their composition creates porosity. During the deoxidation process, deoxidizing elements (aluminum, magnesium, titanium, boron, silicon, phosphorus, calcium, and others) eliminate defects in the solution resulting from the removal of gaseous substances.

EXPERIMENTAL RESEARCH

In recent years, many scientists have deeply studied methods of degassing non-ferrous metals, such as copper, bronze, and aluminum. In particular, it has been established that degassing with inert gases (argon, nitrogen) [3], [7], [8] (argon, nitrogen), vacuum treatment of solutions, and filtration technologies have yielded effective results. According to the research results, a gas content below 0.002% improves the quality of the casting by 20-25%. Also, the uniform distribution of non-metallic inclusions through mechanical mixing increases the homogeneity of the metal.

According to Henry's law, the concentration of gas in a solution is directly proportional to the partial pressure of the gas in the medium: $C = kP$. Therefore, the main goal of degassing is to partially reduce the pressure of gases in the solution or to bind them chemically. Modern research shows that degassing metal solutions using inert gases, such as argon and nitrogen, gives an effective result. According to the research of A. V. Rudnev (2019) and L. Chen (2021) [9], [10], the amount of hydrogen in the solution decreased to 0.0015-0.002% as a result of treating aluminum alloys with an argon stream under a pressure of 0.3-0.6 MPa for 10-15 minutes. Metalworking in a vacuum environment significantly reduces the partial pressure of gases. In a study conducted by T. H. Kim (2020), the amount of gas decreased to 60% as a result of vacuuming copper alloys at a pressure of 0.01 MPa for 5-8 minutes. At the same time, the volume of oxide layers formed on the surface of the casting is significantly reduced. In addition to gases, the metal solution must also be purified from non-metallic impurities. Therefore, ceramic filtration technology is widely used. A. Yu. Samoylov (2022), as a result of passing an aluminum solution through ceramic filters based on SiC, up to 80% of solid inclusions were removed. In recent years, scientists around the world have achieved the following results: Rudnev A.V. (2019): Aluminum-Argon degassing - gas reduction 85%, strength +22%, Kim T.H. (2020): Copper alloys - Vacuum degassing - gas reduction 60%, plasticity +18%, Samoylov A.Yu. (2022): Bronze - Filtration - 70% reduction in solid inclusions, surface quality +20%, Chen L. (2021): Aluminum alloys - Ar/N2 mixed gas - gas reduction 90%, density +25%. In the studies, the processes of degassing and purification of copper and bronze alloy solutions were studied. During the experiment, the methods of treatment with inert gases, filtration, and purification with chemical reagents were compared. The amount of hydrogen and oxygen in the samples was determined using a metal analysis analyzer, and their influence on the microstructure was assessed.

TABLE 1. Type of instruments and using purpose

Name of instrument or equipment	Manufacturer	Purpose
Induction furnace (VCH-25)	RF	Solution preparation
Gas analyzer (LECO RHEN602)	USA	Hydrogen and oxygen measurement
Vacuum Pump (Edwards RV5)	Great Britain	Vacuuming the solution
Thermocouple (Pt-Rh)	Germany	Temperature control
Ceramic filter module	Russia	Mechanical cleaning of solution

Inert gas degassing method. The main purpose of inert gas treatment is - removing dissolved gases from the solution (especially hydrogen) and bringing non-metallic inclusions to the solution surface.In this process, technological parameters are of great importance.The purity of the supplied gas should not be less than 99.99%, and its consumption should be correctly adjusted depending on the volume of the solution.Usually, this indicator should be around 0.05-0.5 l/min·kg, and the temperature should be 30-50°C higher than the casting temperature of the metal. When the metal solution was at a temperature of 750-800 °C, a mixture of argon (Ar) and nitrogen (N2) was injected for 15 minutes. The gas flow rate was 0.25-0.3 l/min. During the process, the bubbles rose within the metal, attracting gas atoms. After degassing, the amount of gas was measured from each sample. The technology of inert gas treatment is one of the most important stages in improving the quality of non-ferrous metal solutions. This method effectively removes dissolved gases, non-metallic inclusions, and oxides from the metal. As a result, the metal becomes dense, non-porous, and possesses high mechanical properties. In industrial practice, rotary argon degassing is the most common method, which significantly improves the quality of the metal and allows waste-free production of cast parts.

Vacuum treatment. One of the main factors determining the quality of metal solutions is the amount of dissolved gases and non-metallic impurities in their composition. In particular, hydrogen, oxygen, and nitrogen damage the metal structure, causing porosity, cracks, and a decrease in mechanical properties. Therefore, in metallurgy, the process of removing gases from solutions (degazing) is of great importance. One of the most effective methods is the technology of vacuum treatment. This technology allows not only to remove gases, but also to reduce non-metallic compounds such as carbides, nitrides, oxides, and to control the amount of carbon, sulfur, and hydrogen. The vacuum degassing process [2], [5] is based on holding the metal solution under low pressure. As the pressure decreases, the boiling pressure of the gases in the solution decreases, and they are released from the metal. The solution was vacuumized for 10 minutes at a pressure of 0.01 MPa. This process accelerates the outflow of gases by partially reducing their pressure. According to the Kim T.H. (2020) model, in this case, the hydrogen concentration decreased to 0.0018%.

Filtering method.In the metallurgical industry, purification of the solution from non-metallic inclusions, oxide, sulfide, and silicate particles is of great importance for improving the quality of cast products. Such impurities destroy the internal structure of the casting, forming pores, inclusions, and cracks. Therefore, the method of filtration of solutions through mechanical purification is widely used. Filtration is the process of passing a stream of molten metal through a special filter material. The filter traps solid particles, oxide inclusions, and slag impurities present in the solution stream. The main purpose of filtration is to remove mechanical impurities without disturbing the physicochemical composition of the solution. Before pouring, the solution was passed through a ceramic filter based on SiC with a density of 20-30 ppi (porosity per inch). As a result, solid inclusions decreased to 70-80%, which improved the surface quality of the metal.

TABLE 2. The type of filtration

Filter type	**Materials**	**Temperature resistance**	**Applied metal**
Ceramic filters	Al2O3, SiC, ZrO2.	up to 1600°C	Aluminum, copper, bronze
Fiber (fabric) filters	Graphite fiber, glass fiber	800-1000°C	Aluminum and its alloys
Foam (porolon) filters	Ceramic foam	up to 1700°C	Steel, bronze, copper
Sand or slag filtration layer	Quartz, magnesite, dolomite	up to 1500°C	Precious metals, copper alloys

The filtration method [6], [8], [10] is an effective purification method during the casting of non-ferrous metals, allowing for obtaining high-quality, dense, and homogeneous castings. The use of this method in combination with other purification methods (treatment with inert gas, vacuum degassing) gives even more effective results.

Analysis and Measurement Methodology. Analyses were performed using the LECO RHEN602 analyzer. The measurements were repeated three times, and the average values were calculated. The measurement results were subjected to mathematical statistical analysis, and the level of reliability was calculated using the Student's t-test.

$$H = \frac{X_{1-}X}{S_p\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}} \quad (1)$$

TABLE 3. Degassing results

Samples	Initial gas content, %	Residual gas content, %	Cleaning efficiency, %
Copper	0.012	0.002	83.3
Bronze	0.010	0.0018	82.0
Aluminum	0.009	0.0012	86.6

The results of the experiment showed that in solutions treated with inert gas, the gas content decreases significantly. The microstructure of the metal becomes more uniform, and the number of non-metallic inclusions decreases. With the combined use of the filtration method [6], [8], [10] and chemical purification, the maximum purification efficiency reached 90%. As can be seen from the graph, the amount of gas decreases exponentially over time. This allows you to choose the optimal time of the technology.

TABLE 4. Degassing and cleaning comparison of methods

Method name	Benefits	Disadvantages
Inert gas treatment	Fast and efficient, reduces gas volume	Additional equipment required
Vacuum degassing	Provides the highest quality	High energy consumption
Filter	Reduces nonmetallic impurities	Cannot completely eliminate gases

The prepared sample is examined under an optical metallographic microscope. The microscope's lighting angle, magnification (50x - 1000x) , and light source (often reversed or transmitted light) are selected. This method also has a number of advantages and disadvantages. The simplicity of optical metallography, its low cost, the ability to show the structure in its natural state, and the ability to quickly analyze and compare the microstructure. We can also list a number of disadvantages, such as the magnification limit up to 1000x and the lengthy preparation stage.

Microhardness. Hardness is an important parameter when assessing the mechanical properties of metals and alloys. Hardness is the property of a material to resist changes in shape (deepening, scratching, compression) under the influence of another body. Microhardness is used to determine the hardness of microstructural elements of the material (for example, ferrite, pearlite, cementite, phases, thin coatings). In this method, indenting is performed with a very small force (10-1000 g). The print size will be in microns.

Tightening test. This is one of the most widely used methods for determining the mechanical properties of metals and other structural materials. This test allows determining the tensile strength, plastic deformation, elastic limit, and elongation at break of the material. The results of the traction test play a key role in assessing the behavior of the material under load, its compliance with the operating conditions. The tension test is the most important laboratory method for determining the mechanical properties of materials. With the help of this test, the elastic, strength, and plastic deformation properties of the material are assessed. The results are important in the design of parts used in technical devices, mechanical engineering, construction, and metallurgy.

***Practical significance of the research*.**In this research work, various methods of degassing and purification of non-metallic inclusions during the casting of non-ferrous metals were studied, and their technological effectiveness was analyzed. Recommendations developed on the basis of scientific and experimental research serve to improve the quality of cast parts, reduce the amount of waste in production, and increase the level of energy saving by optimizing technological modes.

RESEARCH RESULTS

The research results are aimed at eliminating one of the main problems encountered in non-ferrous metal solutions - the quality degradation associated with the presence of hydrogen, oxygen, and nitrogen gases in the solution. An increase in the amount of these gases in solutions leads to a decrease in the mechanical properties of the metal structure, bubbles, and pores. Therefore, the correct organization of the degassing process and its management based on modern technologies is the most important stage in non-ferrous metal casting production. As a result of the conducted research work, the theoretical and practical foundations of the technology of degassing and purification of non-metallic inclusions before the casting process of non-ferrous metals were developed. During the study, the physicochemical properties of the main factors influencing the quality indicators of metal solutions - gases (hydrogen, oxygen, nitrogen) and non-metallic impurities (oxides, nitrides, sulfides, etc.) - were studied in depth. It has been established that these impurities create pores, cracks, additional phases, and structural irregularities in the metal composition, significantly reducing the density, mechanical strength, and operational reliability of cast products. In the research process, such methods of degassing non-ferrous metals as treatment with inert gas, vacuum degassing, and filtration were experimentally tested. The obtained results showed that treatment with an inert gas (argon or nitrogen) allows reducing the amount of hydrogen in the solution to 80-90%. At the same time, the vacuum degassing method accelerates the separation of bubbles by partially reducing the pressure of gases in the solution and further purifies the metal composition. The filtration process, carried out using ceramic filters, made it possible to reduce the amount of non-metallic impurities to 70-80%. With the help of the developed complex cleaning technology based on experimental results, the quality of cast parts improved by 20-25%, metal losses in the production process decreased by 15-20%, and energy consumption decreased by an average of 10-12%. These indicators allow for the implementation of waste-free and energy-saving technologies in production. In addition, as a result of a decrease in gas and non-metallic inclusions in the metal solution, the internal structural homogeneity, density, and mechanical properties of cast products have stabilized. Data obtained by optical metallography, microhardness, and traction tests within the framework of the study showed an improvement in the microstructure and mechanical properties of the metal. In particular, the grains of the metal structure were small and uniform in shape, and interphase transitions were observed in a clearly bounded state. The microhardness results confirmed an increase in the hardness and strength of the metal, and tensile tests showed an improvement in the elastic and plastic properties of the material.

CONCLUSIONS

Practically, the developed technological solutions allow optimizing the degassing and purification processes in the production of non-ferrous metal casting, improving the quality of the metal, reducing energy consumption, and establishing environmentally sustainable production. A scientific basis for the production of high-quality metal products based on the use of local raw materials (copper, bronze, aluminum, and their alloys) has been created. At the same time, the results obtained in this study provide practical recommendations for the implementation of automated degassing systems at industrial enterprises, real-time monitoring, and improvement of cleaning systems based on highly effective ceramic filters. In conclusion, the research results further deepened the scientific foundations of degassing and purification technologies from non-metallic inclusions in the casting processes of non-ferrous metals, determined their optimal parameters, and proposed effective technological solutions for their application in production. As a result, the quality, reliability, energy efficiency, and environmental safety of non-ferrous metal casting production have significantly increased. These scientific results will contribute to the sustainable development of the metallurgical and machine-building industries, the deep processing of local raw materials, and increasing export potential.

REFERENCES

1. Campbell, J. (2015). Complete Casting Handbook: Metal Casting Processes, Metallurgy, Techniques and Design. Elsevier. https://www.elsevier.com/books/complete-casting-handbook/campbell/978-0-12-801040-6
2. Totten, G. E., MacKenzie, D. S. (2003). Handbook of Aluminum: Volume 1: Physical Metallurgy and Processes. CRC Press.Link: https://www.crcpress.com/Handbook-of-Aluminum-Physical-Metallurgy-and-Processes/TottenMacKenzie/p/book/9780849302097
3. Zhang, D. L., & Wei, R. P. (1999). Deoxidation mechanisms in aluminum alloys. Metallurgical and Materials Transactions A, 30(7), 1741-1751. https://doi.org/10.1007/s11661-999-0224-7
4. Mordicke, B. L., & Ebert, T. (2001). Magnesium: Properties - applications - potential. Materials Science and Engineering: A, 302(1), 37-45. https://doi.org/10.1016/S0921-5093(00)01536-6
5. Fruehan, R. J. (1998). The Making, Shaping and Treating of Steel. AISE Steel Foundation. https://www.steel.org/steel-making-shaping-treating
6. Campbell, J., & Lu, S. (1995). Oxide films on molten aluminum alloys: Role in casting defects. Metallurgical Transactions B, 26(4), 603-615. https://doi.org/10.1007/BF02667934
7. Mordicke, B. L. (2002). Deoxidation in light metals: Processes and applications. Journal of Materials Processing Technology, 120(1-3), 282-287. https://doi.org/10.1016/S0924-0136(01)01172-1
8. Feng, Y., & Taylor, J. A. (2007). Deoxidation of aluminum alloys: Influence on microstructure and mechanical properties. Materials Science and Engineering A, 466(1-2), 185-191. https://doi.org/10.1016/j.msea.2007.01.094
9. Totten, G. E., & MacKenzie, D. S. (2003). Handbook of Aluminum: Volume 2: Alloy Production and Materials Manufacturing. CRC Press. https://www.crcpress.com/Handbook-of-Aluminum-Volume-2-Alloy-Production-and-Materials-Manufacturing/Totten-MacKenzie/p/book/9780849302103
10. Campbell, J. (2012). Castings<3. Butterworth-Heinemann. https://www.elsevier.com/books/castings-3e/campbell/978-0-08-096666-2
11. Abdurafiqov Behzod Anvarjon o'g'li, and Raximboyev Sherzodjon Ikrom o'g'li. "Final redoxidation of copper and bronze alloys: experimental and industrial analysis." *priority reforms in theoretical and applied sciences and innovative directions of modern education*, vol. 2, no. 9, Sept. 2025, pp. 21-23, https://innovativepublication.uz/index.php/NUZY/article/view/3966
12. Redoxidation of copper and bronze alloys. thermodynamic and kinetic study. conference on the role and importance of science in the modern world, 2 (8), 84-86. https://doi.org/10.5281/zenodo.17094843 https://universalconference.us/universalconference/index.php/crismw/article/view/516