



Optimal Design of Lining For A Medium-Frequency Induction Furnace

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Abstract: This article analyzes the issues of optimal design of the lining for a medium-frequency induction furnace. One of the main problems considered is the wear of the lining, its service life, and the change in its thermal resistance during the melting of ferrous metals and their alloys in induction furnaces. The study examines the selection of optimal lining thickness, the proper organization of gunning (repair) processes, and their impact on production efficiency. In addition, a number of assumptions are introduced for the operational model of the process, and approaches aimed at improving the performance of the lining are proposed. As a result, the importance of lining parameters and maintenance strategies in ensuring the optimal operating conditions of the furnace is substantiated.

Keywords: Induction Furnace, Medium Frequency, Lining, Crucible, Thermal Resistance, Melting, Gunning (Repair), Wear, Optimal Thickness, Energy Efficiency, Metal Scrap, Technological Process.

Introduction

In induction furnace plant used for melting ferrous metals and their alloys, furnaces with relatively small capacities are widely applied. In these shops, furnaces are mainly used for remelting secondary charge materials. Medium-frequency (500÷10,000 Hz), coreless induction furnaces – i.e., furnaces without a metallic core in the center of the crucible (Fig. 1) – based on solid-state technology currently constitute the main share of induction furnaces. This article focuses on the lining materials used in a medium-frequency induction melting furnace. Medium-frequency furnaces produced by various manufacturers are most commonly used with capacities ranging from 250 kg to 5 tons.

Methodology

Induction heating is a phenomenon that occurs under the influence of a rapidly changing, high-intensity magnetic flux. In the remelting of metal scrap, induction furnaces have certain advantages over arc furnaces commonly used for the same purpose. However, one of the main problems in the operation of medium-frequency induction furnaces is the rapid wear of the coreless lining and the time required for its repair. Nevertheless, practical experience shows that the efficiency of the process can be improved through well-planned

and systematic maintenance of the lining. Various aspects of electric steel production, especially those related to arc furnaces, have been widely discussed in the literature. However, this particular issue has not yet been sufficiently studied.



Fig. 1. Medium-frequency coreless induction furnace

The lining is prepared by installing a cylindrical metal shaping sheet in the center of the crucible and filling the resulting cavity with refractory materials, which are then densely packed. After this, a heating process lasting 10÷14 hours is carried out. During heating, the metal melts similarly to the regular melting process, but at a lower power. In many cases, the metal sheet also melts during the heating process. In some technologies, special mechanisms are used that allow the sheet to be removed and reused. To extend the service life of the lining, periodic gunning (repair) operations are performed. Gunning is carried out in a manner similar to preparing a new lining, after the lining has partially worn. In this process, the lining is not completely destroyed. Gunning takes approximately 4 hours and consumes less refractory material. Between two gunning operations, remelting is typically performed 20÷40 times, with each remelting lasting 1÷2 hours. After several gunning cycles, prolonged operation at high temperatures reduces the thermal resistance of the lining, and ordinary gunning is no longer sufficient to compensate for this loss. In such cases, a new lining must be prepared. Sometimes, gunning efficiency decreases even earlier, meaning the number of remelting operations possible after each gunning is reduced. In addition to the decrease in thermal resistance, the furnace efficiency reaches its maximum when the lining has an optimal or near-optimal thickness. Therefore, to increase the number of remelting operations at this optimal condition, gunning must be performed frequently. However, this slows down the process and increases costs.

Decisions such as the initial thickness of a new lining, the thickness after gunning, and the sequence in which gunning operations should be performed are crucial for achieving maximum furnace efficiency. Additionally, a well-designed lining structure and a proper maintenance schedule help prevent any serious operational problems.

Result and Discussion

To carry out the operational analysis of the process, the following assumptions are made, taking into account the situations discussed above:

1. It is assumed that the furnace contains a single crucible and a single dust generator.
2. A single type of metal scrap is melted, producing one type of steel, and in each melting, only one type of slag-forming material is used. At the same time, the same type of lining is employed. The wear of the lining depends on all the factors described above. However, these factors may remain constant in many operational processes, especially if multiple types of melting are not performed, which reduces lining wear [19]. Workshops based on induction furnaces typically produce a limited range of steel grades.
3. When a new lining is installed, its condition is considered "new." The "damaged" state refers to a lining that has developed deep cracks and can no longer be used. All other conditions are described as "intermediate" states.
4. When melting or heating is performed, the lining melts with a probability determined by its thickness t and the type of operation a , corresponding to a thickness reduction of $\Delta t(t, a)$ and a probability $p\Delta(t, a, n)$, or it transitions to a "damaged" state with a probability of $1 - p\Delta(t, a, n)$. Here, n is the sequential number of melting operations. The possible operations are: (a) preparing a new lining; (b) melting/heating; (c) gunning (repair). When the lining is assumed to melt, $\Delta t(t, a)$ is taken as a definite quantity, and its random variations are not considered; it represents an average value.
5. The duration of preparing a new lining, melting, or gunning (repair) is random, with the average duration depending on the type of operation and the thickness of the lining [20].
6. If no cracks occur, the average costs of operations depend on the thickness of the lining. The cost of preparing a new lining includes refractory materials, repair, energy consumption, as well as revenue from the amount of metal produced, excluding the cost of the charge materials used. The average costs of melting or gunning are determined in a similar manner. One factor affecting costs and time is how the charge materials are loaded into the furnace. When accounting for energy consumption, additional expenses such as pumps for cooling water, air conditioners, or pollution control equipment must also be included. When the lining reaches a "damaged" state, the costs and time are considered such that the ratio of cost to time becomes significantly high.
7. The thermal resistance of the lining can be determined by taking into account its initial thickness, the thicknesses during melting/heating, the temperature and duration of these processes, as well as the timing of gunning (repairs). The thermal resistance of the lining must remain above a specified minimum value, R_{min} .

The minimum value R_{min} can be determined analytically using heat transfer models, based on the allowable maximum temperature of the crucible's outer surface. To calculate the thermal resistance of the lining, it can be assumed to consist of thin layers, so that the temperature within each layer remains uniform. The relationship between temperature increase and the corresponding change in thermal conductivity during heat transfer is assumed and should be verified experimentally. If random variations in temperature and heating duration occur, the maximum temperature and time must be considered for safe design. However, for a given lining thickness, these variations do not produce significant differences.

Conclusion

In medium-frequency induction furnaces, the optimal design of the lining plays a key role in improving production efficiency. The study results indicate that selecting the correct lining thickness and performing gunning operations at optimal intervals can significantly enhance furnace performance. Excessive thinning of the lining increases heat losses, while excessive thickness leads to higher energy consumption. Therefore, determining and maintaining the optimal thickness is essential.

Additionally, properly organizing the maintenance strategy of the lining, that is, performing gunning operations on time, extends its service life and prevents unexpected failures. Overall, scientifically selecting and managing lining parameters ensures the efficient and reliable operation of induction furnaces.

References

- Khasanov, J., Kholmiraev, N., Saidmakhamadov, N., Tojiboev, B., Dilshodbek, E., Makhammadjanov, K., ... & Otakuziev, A. (2024). Development of technology for obtaining thin-walled details from gray cast iron in sand-clay moulds. *International Journal of Mechatronics & Applied Mechanics*, (18). <https://doi.org/dx.doi.org/10.17683/ijomam/issue18.24>
- Kholmiraev, N., Saidmakhamadov, N., Khasanov, J., Tadjiev, N., Yusupov, B., Sadikova, N., ... & Nurdinov, Z. (2024, December). Mathematical Modeling of the Effect of TiC Nanopowder Particles on the Wear Resistance Properties of Low-Alloy Steel. In *Materials Science Forum* (Vol. 1139, pp. 11-19). Trans Tech Publications Ltd. <https://doi.org/10.4028/p-gIS27O>
- Kholmiraev, N., Turakhodjaev, N., Saidmakhamadov, N., Khasanov, J., Bektemirov, A., & Sadikova, N. (2024). Effects of titanium (Ti) contents on the wear resistance of low-alloy steel alloys. In *E3S Web of Conferences* (Vol. 525, p. 03003). EDP Sciences. <https://doi.org/10.1051/e3sconf/202452503003>
- Kholmiraev, N., Turakhodjaev, N., Saidmakhamadov, N., Khasanov, J., Saidkhodjaeva, S., & Sadikova, N. (2023). Development of Technology of Making Shafts from Steel Alloy 35XGCL. *Lecture Notes in Networks and Systems*, 762 LNNS. https://doi.org/10.1007/978-3-031-40628-7_18
- Kholmiraev, N., Turakhodjaev, N., Saidmakhamadov, N., Tadjiev, N., Khasanov, J., Yusupov, B., ... & Juraev, J. (2024, December). Improvement of the Technology of Melting of Low Alloy Steel Alloy in an Electric Arc Furnace. In *Materials Science Forum* (Vol. 1139, pp. 3-9). Trans Tech Publications Ltd. <https://doi.org/10.4028/p-2AMBsZ>

- Nodir, T., Nosir, S., Shokhista, S., Furkat, O., Nozimjon, K., & Valida, B. (2021). Development of 280X29NL alloy liquefaction technology to increase the hardness and corrosion resistance of cast products. *International Journal of Mechatronics and Applied Mechanics*, 1(10). <https://doi.org/10.17683/IJOMAM/ISSUE10/V1.19>
- Nosir, S., & Bokhodir, K. (2022, August). Development of liquefaction technology 280X29NL to increase the strength and brittleness of castings. In *International Conference on Reliable Systems Engineering* (pp. 105-115). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-15944-2_10
- Saidmakhamadov N., Abdullaev K., Abdullayev B., Khasanov A. Development of technology for obtaining quality castings from steel alloys *Eurasian Journal of Engineering and Technology* // ISSN: 2795 – 7640 Volume 5| April, 2022 <https://geniusjournals.org/index.php/ejet/article/view/1273>
- Saidmakhamadov N., Abdullaev K., Khasanov J., Adkhamov Kh. Development new brands of resistance white cast irons. *European Journal of Research Development and Sustainability (EJRDS)* Available Online at: <https://www.scholarzest.com> Vol. 3 No. 1, January 2022 ISSN: 2660 – 5570 <https://scholarzest.com/index.php/ejrds/article/view/1779>
- Saidmakhamadov N., Abdullaev K., Khasanov J., Bulitova Sh. Development of 280X29NL brand resistance white cast iron liquefaction technology «Теория и практика современной науки» №1(79) 2022 <https://cyberleninka.ru/article/n/development-of-280x29nl-brand-resistance-white-cast-iron-liquefaction-technology>
- Saidmakhamadov N., Bekchanova V., Turakhodjaev N., Rizaeva N., Turaev A Improvement of the Technology of Production of Quality Semi – Finished Product Products from Steel Alloy *European multidisciplinary journal of modern science* ISSN 2750-6274 <https://emjms.academicjournal.io> Volume: 9 August-2022 <https://oldemjms.academicjournal.online/index.php/emjms/article/view/748>
- Saidmakhamadov N., Karimov B., Hudoykulov Sh., Bekjanova L Development of high chromium white cast iron liquefaction technology *Eurasian Journal of Engineering and Technology* Volume 4| March, 2022 ISSN: 2795 – 7640 www.geniusjournals.org. – p. 123 – 124. <https://geniusjournals.org/index.php/ejet/article/view/912>
- Saidmakhamadov N., Khalimjonov T., Saidkhodjaeva Sh., Turaev A Technology for Obtaining High – Quality Castings from Resistance White Cast Iron. *Eurasian Journal of Engineering and Technology* // ISSN: 2795 – 7640 Volume 5| April, 2022 <https://geniusjournals.org/index.php/ejet>
- Saidmakhamadov N., Turakhodjaev N., Abdullaev K., Khasanov J., Tadjiev N Improvement of Technology of Liquefaction of Gray Cast Iron Alloy. *Global Scientific Review A*

Peer Reviewed, Open Access, International Journal www.scienticreview.com
Volume 6, August 2022 ISSN (E): 2795-4951
<https://scientificreview.com/index.php/gsr/article/view/40>

Saidmakhamadov N., Turakhodjaev N., Abdullaev K., Saidkhodjaeva Sh., Tadjiev N
Improving the technology of liquidation of wear – resistant white cast iron.
International Journal of Innovations in Engineering Research and Technology
<https://repo.ijert.org/index.php/ijert/article/view/3359>

Saidmakhamadov N., Turakhodjaev N., Zokirov R., Abdullaev K., Saidkhodjaeva Sh
Study of the Effect of Copper Addition on Secondary Carbides with High Chromium Wear
– Resistant White Cast Iron. International Journal of Innovative Analyses and
Emerging Technology |e-ISSN: 2792-4025 <http://openaccessjournals.eu> Volume: 2
Issue: 6 ISSN 2792- <https://oajournals.net/index.php/ijiaet/article/view/1486>

Saidmakhamadov N., Zokirov R., Abdullayev B., Zufarova N. Technology to increase the
hardness and resistance of high – chromium white cast iron. European
multidisciplinary journal of modern science
<https://emjms.academicjournal.io/index.php/Volume:6>

Saidmakhamadov Nosir, Karimov Bokhodir Development of Liquefaction Technology
280X29NL to Increase the Strength and Brittleness of Castings. International
Conference on Reliable Systems Engineering (ICoRSE) - 2022 pp 105–115
https://link.springer.com/chapter/10.1007/978-3-031-15944-2_10

Saidmakhamadov, N., Kholmiraev, N., Bekchanova, V., Odilov, F., Tukhtaboev, I.,
Gaybullaev, M., ... & Eshimov, D. (2025, February). Mathematical modeling of the
influence of the gating system on the quality of the cast product during alloy casting.
In AIP Conference Proceedings (Vol. 3268, No. 1, p. 030002). AIP Publishing LLC.
<https://doi.org/10.1063/5.0257618>

Saidmakhamadov, N., Turakhodjaev, N., Tursunbaev, S., Zokirov, R., Tadjiev, N.,
Abdullaev, K., ... & Juraev, J. (2024). Improving the design of the lining of the ball
mill used to improve the quality of grinding. In E3S Web of Conferences (Vol. 525, p.
02017). EDP Sciences. <https://doi.org/10.1051/e3sconf/202452502017>