International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V72I7P101

Volume 72 Issue 7, 1-10, July 2024

Original Article

Reduction of the Ferroalloy Fines Formation Due to the Usage of a New Casting Mould Configuration

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Received: 16 March 2024 Revised: 15 May 2024 Accepted: 18 June 2024 Published: 26 July 2024

Abstract *- The relevance of the new casting mould configuration usage for reducing ferroalloy fines formation is conditioned by increasing efficiency and environmental sustainability in the metallurgical industry, where waste reduction and resource conservation are of high interest. The purpose of this study is to investigate the impact of a new casting mould configuration on the ferroalloy smelting process to determine its potential to reduce the ferroalloy fines formation and increase the efficiency of metallurgical production. The methods used include analytical method, classification, functional method, statistical method, synthesis, etc. As part of the study, industrial tests of cellular casting moulds were carried out at the Aksu Ferroalloy Plant, a branch of "TNC Kazchrome" JSC, in order to optimise the casting process of various ferroalloys. This research included a detailed comparative analysis of the substandard fines formation process during casting using moulds of various configurations. The study results revealed the optimal casting mould configuration, which can significantly reduce the formation of substandard fines during ferroalloy casting. This is a significant achievement of key importance for the metallurgical industry, as it reduces material losses and increases production efficiency. Thus, the study confirms that the introduction of a new casting mould configuration can optimise production processes in the metallurgical industry. The data and conclusions obtained in this study can be applied in the metallurgical industry to optimise processes and reduce losses, thereby improving economic efficiency and reducing negative environmental impact.*

Keywords *- Metallurgy industry, Industrial testing, Environmental sustainability, Production, Mechanical strength.*

1. Introduction

The persistent challenge of ferroalloy fines formation poses a significant obstacle in the metallurgical industry, leading to material losses and reduced production efficiency. Moreover, amidst escalating environmental concerns and the imperative to curtail waste generation, the need for innovative solutions is more pressing than ever. The investigation of novel casting mould configurations emerges as a promising avenue to address this dual challenge, yet a conspicuous research gap persists in this domain. While the metallurgical sector plays a pivotal role in supplying materials essential to diverse economic sectors, its efficacy profoundly influences global market competitiveness and sustainability. Against this backdrop, this study endeavours to bridge this research chasm by pioneering new methodologies and technologies in casting mould construction. By concurrently mitigating ferroalloy fines formation and aligning with stringent environmental standards, our research aims to bolster industry efficiency and alleviate its environmental footprint. This concerted effort holds promise for fostering more resilient and sustainable production systems, thereby yielding benefits that reverberate across both the industry and society at large. R. Kozhamuratov et al. [1] underscore the criticality of addressing the challenge of processing ferroalloy fines within the context of waste management in ferroalloy production. While their work sheds light on the imperative of waste disposal, a notable gap emerges in their examination: the absence of exploration into techniques and recommendations for ferroalloy manufacturers to adopt new casting mould configurations aimed at mitigating ferroalloy fines formation. This omission represents a significant opportunity for further research and development in the field. By extending the inquiry beyond waste disposal to encompass innovative casting mould designs, future studies can offer actionable insights to enhance both production efficiency and environmental sustainability in the ferroalloy industry.

E. Abdulabekov et al. [2] analyse the technological parameters that influence the ferroalloy fines formation and also propose methods for their reduction. This paper is important for optimising processes in the metallurgical industry. The study did not include monitoring and analysis of the introduction of new casting mould configurations in real production conditions to continuously optimise processes and reduce losses. M. Akhtar et al. [3] underscore the growing importance of environmental sustainability in the development of technologies for fines processing, emphasising the need for stricter environmental standards. While the study offers a method for sintering metallurgical waste, it overlooks the exploration of how different casting mould configurations impact ferroalloy melting and casting processes. This represents a notable gap, as understanding the influence of casting mould designs on efficiency is crucial for identifying optimal solutions in the context of environmental sustainability.

S. Rodivilov et al. [4] contribute to the literature by offering a comparative analysis of different methodologies and assessing their effectiveness, thus furnishing valuable insights for decision-making in methodology selection. However, a noteworthy gap in their research lies in the absence of analysis concerning the environmental implications of utilising new casting mould configurations.

This encompasses a holistic evaluation encompassing not only the potential environmental benefits but also the possible negative consequences, such as emissions and waste generation. By failing to address this aspect, the study leaves a crucial dimension unexplored, which is imperative given the escalating focus on sustainability and environmental stewardship in contemporary industrial practices.

B. Satbaev et al. [5] raise an important question about the constant need to introduce new casting mould configurations to increase production efficiency. Their research focuses on the importance of innovation in the metallurgical industry. However, the study did not cover the development of techniques and recommendations for ferroalloy manufacturers to introduce new casting mould configurations to reduce the ferroalloy fines formation.

N. Aripova et al. [6] make a significant contribution by analysing the technological parameters affecting ferroalloy fines formation and proposing methods for its reduction, thereby offering valuable insights for process optimisation in the metallurgical industry. However, a notable gap in their research is the absence of monitoring and analysis concerning the implementation of new casting mould configurations in real production conditions.

This gap represents a missed opportunity to assess the practical efficacy and challenges associated with integrating innovative mould designs into existing production processes. By neglecting this aspect, the study overlooks the potential for continuous process optimisation and loss reduction, which are crucial considerations for enhancing operational efficiency and competitiveness in the metallurgical sector. The purpose of this study is to assess the impact of the modified casting mould configuration on the ferroalloy smelting process to determine how it can reduce the ferroalloy fines formation and improve metallurgical production efficiency.

2. Materials and Methods

The analytical method played an important role in identifying the key factors influencing the ferroalloy fines formation. Through systematic analysis and data processing, this method allowed the identification of the main variables and conditions that have the greatest effect on the formation of fines in metallurgical practice. Such in-depth analysis, in turn, led to a more complete and accurate understanding of the essence of the original problem, which is an important step in developing effective strategies to reduce the formation of fines in ferroalloy production.

Using statistical methods, the data were analysed to identify the links between various factors and the ferroalloy fines formation. This approach allowed quantifying the impact of each factor and determining their importance during ferroalloy fines formation. Thus, the statistical method provided reliable and objective data that served as the basis for the development of strategies to reduce the ferroalloy fines formation in metallurgical production.

The structural and functional methods helped to deeply investigate the internal relationships and organisation of the metallurgical production system. With its help, the structure of production processes and functions was analysed, which helped to identify the key elements responsible for the ferroalloy fines formation. The study of the structure and functions determined which components of the metallurgical system can be optimised or changed to reduce the ferroalloy fines formation. Thus, the structural and functional method provided a deeper understanding of the production organisation, which served as the basis for the development of effective strategies to improve metallurgical processes and reduce the formation of substandard fines.

The deduction has played an important role in the study of the initial data and the development of logical conclusions regarding the ferroalloy fines formation. Using this method, the study was able to deduce general patterns and logical consequences based on available facts and data. The deduction contributed to the establishment of causal relationships and the identification of the fundamental principles underlying the formation of fines during ferroalloy casting. Such a logical consideration allowed the development of strategies and methods to reduce the formation of fines based on logic and established patterns, which improved the efficiency of metallurgical production. The use of the synthesis created new models and technologies in the metallurgical field, which were aimed at reducing the ferroalloy fines formation. Using this method, the study combined various components and aspects of metallurgical production, creating innovative approaches and systems that help minimise substandard fines. This method enabled the development of new integrated approaches to the management of production processes, which ultimately led to a reduction in material losses and an increase in the overall metallurgical production efficiency. The results of industrial tests conducted on cellular casting mould at the Aksu Ferroalloy Plant, which is a branch of “TNC Kazchrome” JSC, are presented. These tests were carried out in real production conditions, giving the obtained data special importance and practical application. Various types of ferroalloys were smelted using cellular casting moulds at the Aksu Ferroalloy Plant, and the results of these tests serve as the basis for evaluating the effectiveness of a new casting mould configuration and its potential in reducing the substandard ferroalloy fines formation. The following equations were used in this study (1):

$$t_k = (t_h + Q/C + m * t_m)/(1 + m), \qquad (1)$$

Where: t_h – initial casting temperature of the alloy, °C; Q – heat of crystallisation, kJ/kg K; t_m – initial temperature of the casting mould, °C; m – heat capacity of the casting mould, calculated according to the following equation (2):

$$m = M_m * C_m/M_{in} * C_{in}. \qquad (2)$$

A method based on the square root law (3) was used to determine the ingot crystallisation time:

$$X = K * t^{1/2}, \qquad (3)$$

Where: X – thickness of the solid crust; K – crystallisation coefficient, t – solidification time of the ingot.

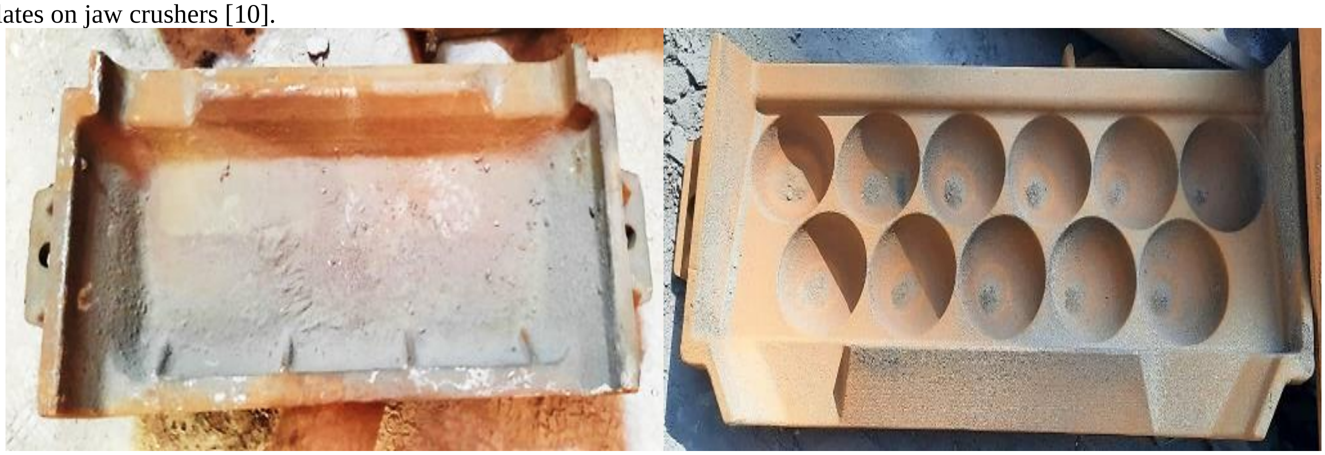
3. Results

Reduction of the ferroalloy fines formation during their processing is important to improve production efficiency in the metallurgical industry. Ferroalloy fines are substandard materials that increase production costs and affect the quality of the final product. In this context, the development and application of new casting mould configurations is an innovative solution that helps reduce the formation of fines in the metallurgical industry. Casting moulds are the key equipment in the metal smelting process. They are structures in which metal solidification takes place, and this process must occur as evenly as possible and without the formation of substandard products. This is where new casting mould configurations become critically important. One of the main problems associated with the formation of fines is the adhesion of metal to the casting mould surface during unloading. Traditional casting moulds usually have a pyramid angle of less than 90°C, which contributes to metal jamming and, as a result, the formation of substandard ingots. The new casting mould configurations with a pyramid angle of 90°C solve this problem, providing a smoother and more efficient outloading of metal. This leads to a decrease in the ferroalloy fines formation. Another important aspect of the new casting mould configuration is the improved organisation of its working surface. This allows using the available space as efficiently as possible, preventing cell overflow and ferroalloy fines formation. More careful management of the casting and solidification processes in the new casting mould configuration allows the creation of continuous layers of ingots, which reduces the formation of substandard products. The new casting mould configuration helps to reduce metal clogging in the cells, especially during casting with a small filling of each cell. This simplifies the process of unloading metal from each cell and reduces the likelihood of fines forming.

The use of new casting mould configurations is an important step in reducing the ferroalloy fines formation in the metallurgical industry. The new configuration contributes to more efficient management of metal casting and solidification processes, reducing the metal adhesion to the casting mould surface and improving the usage of available space. This reduces production costs, improves the quality of final products, and makes the metallurgical industry more competitive in the global market. A variety of metal casting methods are used in the modern metallurgical field, such as the use of casting machines, directing metal into stationary pallets, moulds, and special places for waste treatment, as well as casting layers into special floor moulds or using the “sequence casting” method at specialised landfills. Now, the more common method is considered to be casting ferroalloys on conveyor belt machines, which are used for the production of ferrosilicon, ferrosilicon manganese, carbonaceous ferromanganese, and carbonaceous ferrochrome [7]. This method is characterised by a high degree of automation and productivity, which improves working conditions in the casting area since the metal is poured not with a crane but with the use of special hydraulic tilters located in sealed chambers. However, a significant disadvantage of such conveyor systems is the variable height of the metal drop during casting, which can lead to its splashing. This, in turn, can cause metal losses reaching about 3%. In addition, the quality of the ingots obtained may deteriorate due to the possible spraying of the moulds with lime milk.

Conveyor-cart type machines are widely used for casting high-silicon alloys, modifiers, ligatures, and alloys containing easily oxidisable elements. These devices help reduce metal losses during casting and improve the quality and appearance of the resulting ingots [8]. The machine itself represents a closed loop with trolleys that move along the track. There are special casting mould trays on these trolleys, which ensure the formation of thin ingots. To extract the ingots from the casting mould, they can either be turned over or pushed using a special pusher into a box placed under the mould. The process of fractionating ferroalloys to obtain particles of the required size includes operations such as crushing and size sorting. The choice of a specific type of crusher depends on the physical characteristics of the ferroalloy, such as its hardness and strength. The use of ferroalloys of a certain fractional composition in steel production contributes to the rapid interaction of alloying elements with molten steel and reduces metal losses due to heat transfer into the bucket. Specialised Crushing and Screening Units (CSU) are used to perform crushing and fractionation operations at ferroalloy enterprises. Scientific research in this area confirms the existence of technological and technical solutions in the world practice of ferroalloy production, which are aimed at reducing substandard particle formation [9]. However, the complete elimination of the formation of fines during crushing remains an unattainable goal at the moment. When casting a commodity fraction (with sizes from 10 to 50 mm and 10-80 mm), ferroalloy fines inevitably appear on the CSU (within the sizes of 0-5 mm and 0-10 mm). The proportion of fines ranges from 20% to 40% of the total mass of the metal and varies depending on the alloy type. This significant amount of fines is a serious problem for ferroalloy manufacturers, which underlines the urgency of finding new technical solutions to reduce this indicator.In an effort to reduce the ferroalloy fines formation, improvements were made in the CSU at the Aksu Ferroalloy Plant. An example of such improvements was the transition from corrugated crushing plates to the use of flat plates on jaw crushers [10].

In addition, experiments were conducted with a variety of screens, including annular and rectangular configurations. Based on theoretical and practical knowledge about the crystallisation process of metal ingots, industrial tests were carried out in practice, during which casting moulds of various shapes were used on a casting machine See Figure 1. In compliance with the high productivity of casting machines, it is proposed to introduce modified casting moulds to reduce the ferroalloy fines formation during casting. As a result of a series of industrial tests conducted by experts from LLP "ERG Research and Engineering Centre", it was proposed to use casting moulds with a modified cell structure on casting machines See Figure 2. The main suggested idea associated with reducing the formation of a fine ferroalloy fraction when changing the casting mould configuration was that when a metal ingot falls from the casting machine and subsequently moves, it will be destroyed in narrow areas and broken into smaller pieces [11]. This means that most of the metal will already be divided into fractions before it is crushed, and only a small part of the material will require additional processing See Figure 3.



a) b)

Fig. 1 Types of casting moulds: a) flat; b) hemispherical

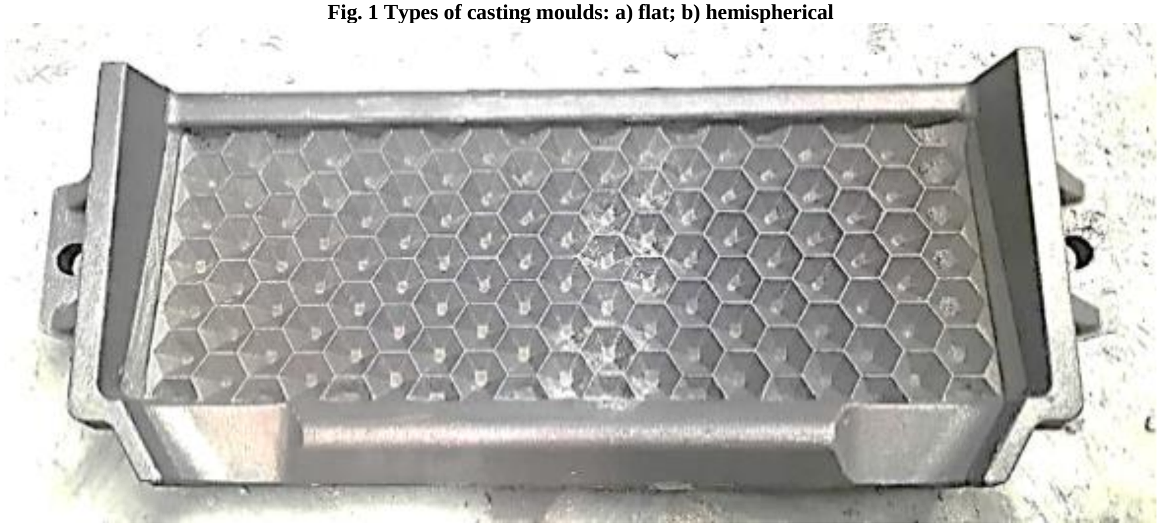
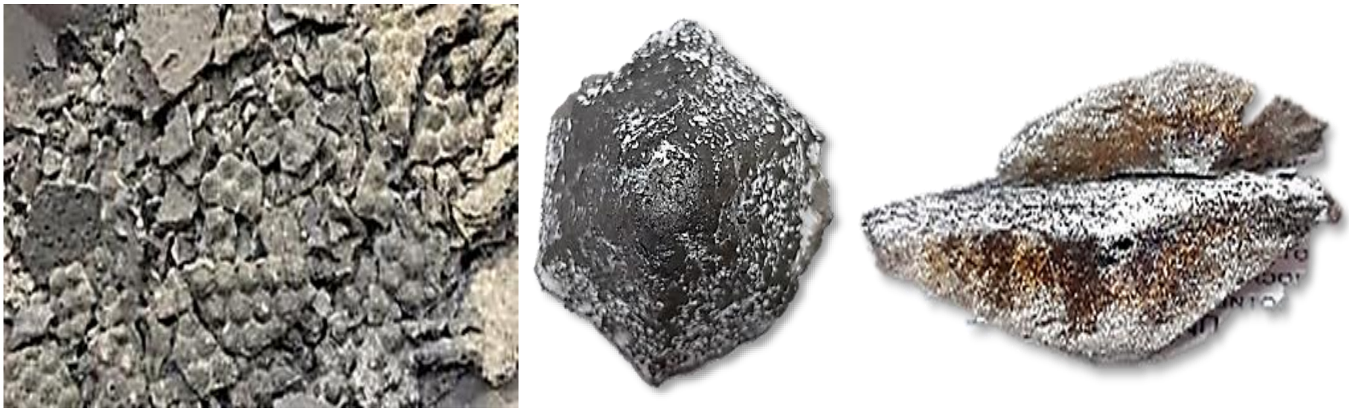


Fig. 2 Experimental cellular casting mould



a) b)

Fig. 3 High-carbon ferrochrome in (a) ingots (b) granules

Fig. 4 Casting machine equipped with cellular casting moulds

The working surface of casting moulds with modified configuration was created in the form of hexagons corresponding to the required size fraction (up to 50 mm) with rounded vertices. This solution led to the most efficient of the casting mould working surface, reduced the metal adhesion to the surface of the casting mould during unloading due to the pyramid angle of 90°C, and avoided clogging of metal in the cells, especially when casting with a small filling of the cell, which contributed to the continuous layer of ingot (5-10 mm) and simplified the metal unloading from each cell.

When developing the structure of the casting mould, it was considered that its main characteristic is the thickness of the walls. This thickness should be adequate for two main purposes. Firstly, it provides the structural strength of the casting mould. Secondly, it allows quick cooling of the melt inside the casting mould to a temperature below the melting point of cast iron. This measure is designed to protect the inner surface of the casting mould from melting and sticking to the ingot. Too much thickness of the walls of the casting mould can lead to an increase in material consumption, which increases the total cost of ingot production [12].

In the course of experiments designed to identify the technological advantages of casting moulds of various configurations, three main criteria were noted: stability, the amount of fine fraction after casting, and the performance of casting machines See Figure 4.

The stability of the casting moulds strongly depends on the heat exchange regime, which is characterised by an average calorimetric temperature tk(1). In relation to the ferroalloy casting process, the use of an average calorimetric temperature is justified by the requirement $X2/X1>1$, where X2 – is the thickness of the casting mould wall, and X1 – is half of the ingot thickness. Depending on the height of the ingot, this ratio varies from 2 to 5, which indicates the forced absence of cooling and justifies the use of the concept of average calorimetric temperature. In this case, tk represents the ambient temperature for both the ingot and the casting mould, at which the surface of the ingot cools down while the casting mould heats up.

According to literature sources [13], after the first solid crust forms on the ingot, it breaks away from the surface of the casting mould due to shrinkage, and tk then represents the temperature existing in the gap between the ingot and the casting mould. M represents the casting mouldheat capacity, which is calculated according to the following equation (2). The casting mould heat capacity during the casting of High-Carbon Ferrochrome (HCF) was 5.05. The average calorimetric temperature tk for the used cellular casting moulds reached 480°C.

A higher tk value indicates more intensive heat exchange in the operation of the mills. It follows from the analysis of equation (1) that the main influence on the thermal regime of the casting moulds is exerted by the value m, while the initial casting temperature of the alloy (in the range of 1550-1600°C) has a less significant effect. The durability of cellular casting moulds was assessed based on the number of fillings. To increase this resistance, lime milk was used as a refractory coating. Table 1 contains the results of tests aimed at assessing the durability of cellular casting moulds before their complete failure. From the analysis of the data, it can be concluded that the durability of cellular casting moulds is comparable to that possessed by flat casting moulds. In addition, when using experimental casting moulds, the productivity of the casting machines is not inferior to the previous one, but to achieve this result, it is necessary to almost double the speed of the belt. The productivity of casting machines depends on two factors: the time required for the crystallisation of ingots and the speed of the conveyor belt [14].

The dependence of the crystallisation coefficient on the temperature on the ingot surface demonstrates that with a decrease in temperature, this coefficient increases, which, in turn, leads to an acceleration of the process of complete crystallisation of the ingot. Two crystallisation fronts of the ingot move during the casting on conveyor casting machines. For the upper crystallisation front, the value of the coefficient K remains constant regardless of the casting mould configuration and is 1.1·10-3 $m/s^{1/2}$, and for the lower crystallisation front, its value corresponds to the data presented in Table 2 according to the equation (3).

The amount of ferroalloy fines was evaluated in two stages: the first stage included only sieving of the material, while the second stage involved additional crushing and subsequent sieving. Data on the output of fines to the CSU are presented in Table 3.

Table 1. Condition of casting mould condition during the tests

No.	Amount of Fillings	Casting Mould Condition
1	180	Condition of casting moulds is satisfactory.
2	284	Casting moulds are in satisfactory condition and are capable of receiving and releasing ferrochrome. Isolated cases of burnt cell edges are observed. The first cracks and partial charring of the cell edges appeared after about 250 fillings, and metal began to penetrate into the deformed areas of the casting moulds, exacerbating the process of metal loss. This defect has been noted in some cases.
3	370	One of the casting moulds was damaged, but the rest of the casting moulds are in satisfactory condition. There are no problems with metal sticking to the casting mould.
4	610	Failure of casting mould.

Table 2. Lower front of crystallisation for casting HCF

Indicator	Casting Moulds	
	Standard	Cellular
K*10-3, $m/s^{1/2}$	1.38	0.82
t_{kr}-s	1080	600

Table 3. Output of fines after crushing and sorting conversion

No.	Alloy	Output of fr. 0-10 mm on flat casting moulds, %	Output of fr. 0-10 mm on cellular casting moulds, %	Deviation, ±
1	Ferrochrome	23.6	14.2	-9.4
2	Ferrosilicon manganese	18.9	13.5	-5.4
3	Ferrosilicochrome-40	37.4	25.9	-11.5
4	Ferrosilicochrome-48	39.8	20.1	-19.7
5	Ferrosilicon-75	18.2	11.6	-6.6

The information presented in Table 3 indicates that cellular casting moulds significantly reduce the output of fines (fr. 0-10 mm) compared with the use of flat casting moulds. The reduction of ferroalloy fines formation during processing is crucial for enhancing production efficiency in the metallurgical industry. These fines, classified as substandard materials, escalate production costs and compromise the quality of the final product. Introducing innovative solutions like new casting mould configurations holds promise in mitigating fines formation, thus presenting a significant opportunity for industry advancement. The primary issue associated with fines formation lies in the adhesion of metal to the casting mould surface during unloading, a common occurrence with traditional mould configurations featuring pyramid angles less than 90°C. This setup often leads to metal jamming and the subsequent formation of substandard ingots. However, the adoption of new mould configurations with a 90°C pyramid angle addresses this problem by facilitating smoother and more efficient metal unloading, consequently reducing fines formation.

The optimised organisation of the working surface in these new configurations maximises space utilisation, preventing cell overflow and fines formation. Improved management of casting and solidification processes results in the creation of continuous layers of ingots, further minimising substandard product formation. Additionally, these new configurations alleviate metal clogging in cells, especially during casting with limited cell filling, simplifying the unloading process and lowering fines formation likelihood. The utilisation of new casting mould configurations marks a significant stride towards reducing ferroalloy fine formation. By enhancing the management of metal casting and solidification processes, these configurations mitigate metal adhesion to mould surfaces and optimise space utilisation. This, in turn, slashes production costs, elevates final product quality, and bolsters the competitiveness of the metallurgical industry globally.

Despite technological advancements aimed at reducing fines formation, complete elimination remains elusive. Current methods inevitably yield fines within specific size ranges, posing challenges for manufacturers. However, ongoing efforts, such as those at the Aksu Ferroalloy Plant, demonstrate progress. Improvements in crushing plates and screen configurations, alongside industrial tests with varied casting mould shapes, exemplify the industry's commitment to innovation. Experimental results suggest that modified casting moulds hold promise in significantly reducing fine formation. The proposed concept revolves around the destruction of metal ingots into smaller pieces upon falling, thereby reducing the need for additional processing. The use of modified moulds with hexagonal cell structures and rounded vertices enhances efficiency, minimises metal adhesion, and ensures continuous ingot layers. The integration of new casting mould configurations presents a viable strategy for mitigating ferroalloy fines formation in the metallurgical industry. These configurations offer enhanced efficiency, reduced production costs, and improved product quality, positioning the industry for greater competitiveness and sustainability.

4. Discussion

The results presented in this study highlight the efficacy of employing new casting mould configurations to reduce ferroalloy fine formation in the metallurgical industry. By introducing modified casting moulds with a pyramid angle of 90°C and improved cell organisation, significant advancements were achieved in mitigating the adhesion of metal to the mould surface during unloading. This, in turn, led to smoother metal outloading and decreased fines formation.

Moreover, the optimised configuration facilitated more efficient usage of available space, preventing cell overflow and promoting the creation of continuous layers of ingots, thereby further reducing the likelihood of producing substandard products. The experimental cellular casting moulds demonstrated superior performance in reducing fines output compared to traditional flat casting moulds. The cellular configuration facilitated the fragmentation of metal ingots into smaller pieces upon falling, thereby minimising the proportion of fines requiring additional processing.

Furthermore, the modified mould design with hexagonal cell shapes and rounded vertices proved instrumental in preventing metal adhesion and cell clogging during casting, contributing to the uninterrupted formation of ingot layers. It's important to note that the durability of the new casting mould configurations was comparable to that of traditional flat moulds, further underscoring their practical viability. Industrial tests revealed that the productivity of casting machines equipped with experimental casting moulds remained competitive, with only a minor adjustment required in conveyor belt speed. This ensured that the efficiency gains achieved through reduced fines formation did not compromise overall production output.

Reducing the ferroalloy fines formation in the casting process is of great importance for saving resources and increasing the efficiency of this industry. One of the methods of reducing this indicator is the use of casting moulds with a modified configuration. The discussion covers the main aspects of this topic. One of the important factors influencing the reduction of fines formation is related to the thermal regime and the structure of the casting form. New casting mould configurations may have improved heat dissipation properties, which contributes to a more uniform cooling and crystallisation of the ferroalloy, thereby reducing the formation of fines. The role of casting moulds in the crystallisation of the ferroalloy is undoubtedly important.

The modified casting mould configuration can accelerate the development of a hard crust on the surface of the ingot, which reduces the likelihood of fine formation during subsequent processing. It is important to note that changes in casting mould configuration can significantly affect its durability and ability to hold ferroalloy ingot. The correct choice of design and material for the casting mould can significantly increase its durability and reduce the formation of fines. Reduction of the ferroalloy fines formation has a direct impact on the economic efficiency of production. Fewer small items mean a higher yield of marketable products, which, in turn, reduces losses and increases profitability. The results of industrial tests and practical observations are important for evaluating the effectiveness of the usage of new casting mould configurations.

They can confirm or refute theoretical assumptions and provide an understanding of which configurations are most suitable for certain conditions. In conclusion, the use of new casting mould configurations is an important step towards reducing the ferroalloy fines formation in production. This helps to improve the efficiency of the process and reduce losses, which has a positive impact on the economic performance of the enterprise. Further research and practical observations in this area can lead to even more effective solutions and reduce the ferroalloy fines formation.

According to J. Sertucha and J. Lacaze [15], the casting of cast iron into sand moulds is a process that ensures the creation of complex cast iron products. Despite its prevalence, the casting process is sometimes subject to various defects that can significantly affect the quality of cast iron workpieces. Especially interesting from the standpoint of research is the study on defects in cast irons in which graphite takes the form of balls since such defects can have a significant impact on the mechanical properties of the material.

Defects associated with cast iron containing spherical graphite may include insufficient filling of the mould with material, formation of inclusions and pores, uneven distribution of chemical components, and problems with thermal conductivity and crystallisation. Each of these defects can cause long-term problems such as reduced strength and compromised sealing.

The study of these defects not only contributes to understanding the mechanisms of their appearance but also to the development of methods and technologies to prevent them. Investigation of defects in spherical graphite cast irons is important for improving the quality of cast iron products and optimising production processes. The development of new control and diagnostic methods allows for more accurate detection of defects, and attention to crystallisation processes and structural analysis helps to identify the roots of these defects and develop methods to prevent them. As a result, cast iron products with spherical graphite can become more reliable and suitable for a wide range of applications, which is important for industrial and engineering industries.

Referring to the definition of D. Aubakirov et al. [16], the study of modifying effects on materials is an important area of research in the metallurgical industry. In this case, it is interesting to consider the effect of the new boron-barium ferroalloy on the wear resistance of low chromium cast iron. Boron-barium ferroalloys are widely used in metallurgy to modify and improve the properties of alloys such as cast iron. It is understood that the addition of boron-barium to cast iron can lead to an improvement in its mechanical and thermal properties, and increased wear resistance.

This may be important for industries in which low-alloy cast iron is used in conditions of high load, friction, and wear, such as steel production, metalworking, and the production of cast products. These data are consistent with the previous section. For a deeper understanding of the effect of the new boron-barium ferroalloy on the wear resistance of cast iron, it is necessary to conduct experiments and analyse the results. Evaluation of changes in the microstructure of cast iron, its mechanical properties, and wear resistance after modification can provide valuable information. This can contribute to the development of more efficient alloys and production processes, which can have an impact on increasing the durability and performance of many industrial devices and mechanisms.

N. Hantke et al. [17] determined that the manufacturability of powder mixtures of tool steel for hot processing during laser welding of the powder layer is an important direction in modern engineering and manufacturing, especially in the field of additive manufacturing and repair of parts. It represents a balanced set of characteristics that includes both the welding quality and weldability of the material and the efficiency and reliability of the process. Powder mixtures of tool steel for hot processing during laser welding of the powder layer have a number of advantages.

First of all, they allow the creation of complex three-dimensional parts with high precision, restoring and reinforcing parts, which reduces costs and production time. However, to achieve optimal results, many factors must be considered, such as the composition of the powder mixture, laser welding conditions, temperature conditions, and other parameters. Analysing the results obtained, effective process control of tool steel powder mixtures includes optimisation of powder mixing and distribution processes, development of suitable welding parameters, quality control of welded parts, and their post-welding processing. It is also important to ensure the durability and quality of the final products.

A. Araoyinbo et al. [18] determined that the powder metallurgy process is an important and widely used technology in the field of production of metal parts and components. It involves the creation of parts from metal powders by pressing, sintering, and subsequent processing. The powder metallurgy process has found wide application in aviation, automotive, medical technology, energy, and other industries due to its ability to create high-quality parts with a variety of characteristics.

As noted by S. Das et al. [19] an important aspect is also the problem of utilisation and sustainable use of ferrochrome slag. On the one hand, it can be perceived as waste and present a recycling problem. On the other hand, with the development of recycling methods and the use of by-products in industry, ferrochrome slag can be considered as a potential source of secondary raw materials [20, 21].

However, this requires the development of technologies that will ensure the safe and efficient use of slag. Ferrochrome slag can be used in construction and road construction as an aggregate and stabiliser. However, it is necessary to ensure that heavy metals do not enter the soil or water resources when used in construction.

Ferrochrome slag is a material with contradictory properties that requires attention in the field of its chemical composition, environmental aspects, and the possibility of sustainable use. Research in this area can contribute to the development of effective methods for managing this material and its introduction into the circular economy. T. Cota et al. have shown that one of the important aspects of using silica manganese slag in alkali-activated materials is its role in reducing environmental impact [20, 22].

Traditional methods of disposal of this slag may include its placement in landfills, which can lead to pollution of the surrounding area. The use of slag in alkali-activated materials may be a more environmentally friendly option, preventing waste and reducing the negative impact on nature. In addition, silica manganese slag can be a potentially valuable element in the production of construction and road materials. Its use can improve the characteristics of materials, such as strength and resistance to water. This can be especially important in construction, where the quality of materials is crucial.

5. Conclusion

The use of casting moulds with a modified configuration significantly affects the ferroalloy casting process. The main hypothesis that a new casting mould configuration allows for reducing the fractionation of metal before the crushing process has been justified. This contributes to the more efficient operation of casting machines and reduces the ferroalloy fines formation.

The conducted studies have shown that the thickness of the casting mould walls has a significant impact on their stability and ability to maintain high productivity. Balancing the wall thickness is an important factor since it ensures the structural strength of casting moulds and rapid cooling of the melt inside them. This balance plays a critical role in the optimising ferroalloy casting process.

The thickness of the casting mould walls should be sufficient to ensure their structural strength and the ability to withstand mechanical loads during casting. It must be configured in such a way as to ensure effective cooling of the melt and prevent melting and welding of the casting moulds to the ingots. Insufficient wall thickness can lead to undesirable deformations and defects in the casting moulds, while excessive thickness can increase material consumption and, as a result, the cost of producing ingots.

Therefore, the precise determination of the optimal thickness of the casting mould walls, considering various process parameters, remains one of the key aspects for further improving ferroalloy casting efficiency and reducing the ferroalloy fines formation. The average calorimetric temperature tk is important for understanding and optimising this process.

Thus, the results of industrial tests have shown that casting ferroalloys using new casting mould configurations leads to a significant decrease in the output of ferroalloy fines. This allows for reducing the ferroalloy fine formation without compromising the performance of casting machines. In general, the use of casting moulds with a modified structure represents a promising way to optimise the ferroalloy casting process, leading to economic and environmental benefits. Therefore, this study provides an important contribution to improving metallurgical production technology and reducing its negative impact on the environment.

The results of the introduction of new casting mould configurations are reflected in the patent of the Republic of Kazakhstan No. 7132 “Ferroalloy casting mould”. For further research in the field of ferroalloy fines reduction when using new casting mould configurations, it is necessary to consider the influence of additional parameters, such as the composition of the material and thermophysical characteristics of the moulds, on the casting process and mould durability.

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