CasTemp®

Dynamic Process Monitoring in the Tundish and Its Impact on Final Product Quality

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ABSTRACT

The steelmaking industry faces multifaceted challenges encompassing cost optimization, energy efficiency, sustainability concerns, and maintaining high-quality standards. In addressing these challenges, the adoption of digitalization strategies emerges as a pivotal solution, revolutionizing traditional manufacturing paradigms. Leveraging advanced technologies such as artificial intelligence and IoT, digitalization facilitates the transition towards manless production environments, streamlining operations and enhancing productivity. This paper explores the significance of dynamic process monitoring in the tundish and its direct influence on the characteristics of the end product. By employing advanced sensors named CasTemp SH control system, operators can continuously monitor key variables such as temperature, superheat, casting speeds, tundish level control and their effects on final product quality.

Keywords: Superheat, CasTemp, Continuous, Casting, Dynamic Control, Steel Production

INTRODUCTION

General Introduction on the Route of Steel Production, Dynamically Controlling Temperature in the Continuous Casting Process and the Safety of Manless Production

Steel is the basic building block of modern industry and is used in many areas such as construction, automotive and energy. World steel production is largely concentrated in Asia, Europe and North America, with China leading the way. The steel industry is intensely competitive and companies are constantly investing in new technologies and process improvements to reduce costs and increase efficiency.

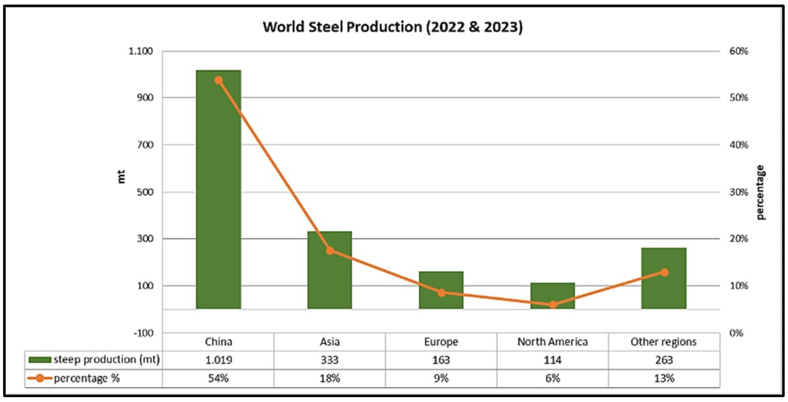

Figure 1. 2022 & 2023 world steel production.

The steel industry is an intensely competitive sector, both locally and internationally. Major producers are constantly striving to reduce costs and increase productivity in order to gain a competitive advantage in the market. This leads them to invest in new technologies and improvements in production processes.

Steel production is a complex process that begins with the melting and refining of raw materials at high temperatures. Continuous casting is the important linking process between steelmaking and rolling. The continuous casting process forms a critical stage of steel production process. It is the most frequently used process to cast not only steel, but also aluminum and copper alloys. Since its widespread introduction for steel in the 1950s, it has evolved to achieve improved yield, quality, productivity, and cost efficiency. Nowadays, the continuous casting ratio has reached the level of 95%. In this method, molten steel is poured into casting moulds in a continuous flow to produce long semi-finished products (billet, bloom or slab). Continuous casting increases production speed, provides energy efficiency and improves product quality, thus reducing costs and increasing productivity in the industry. Continuous casting offers not only a high level of productivity and yield but also improved quality. Research and development work in the field of continuous casting continues intensively, because with the developing more technological world, steel quality requirements are becoming more and more stringent and energy efficiency, productivity and ecological aspects are becoming increasingly important.

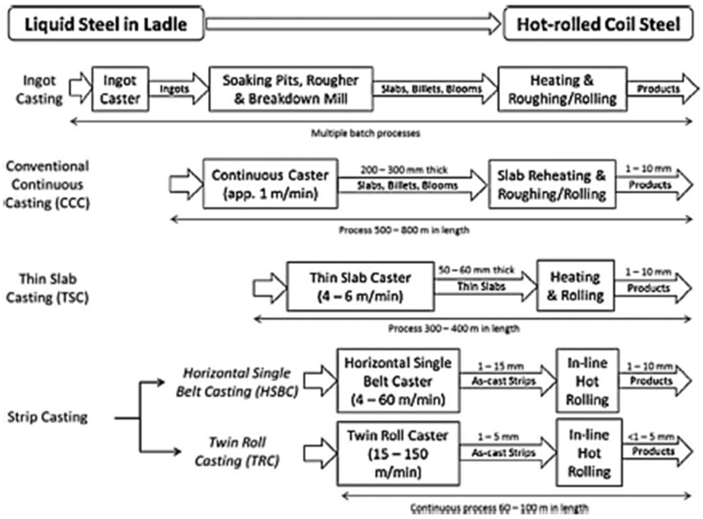

Figure 2. Evolution of Continuous Casting Process. Processing stages and operating parameters of various processes.

Dynamic temperature control is crucial in the continuous casting process, as it directly impacts the quality and consistency of the cast products. Precise temperature regulation helps to maintain the correct solidification rate, preventing defects such as cracks or segregation. By ensuring that the molten metal remains within the optimal temperature range throughout the casting process, dynamic temperature control minimizes the risk of fluctuations that could lead to structural weaknesses. This not only enhances the mechanical properties of the final product but also improves the efficiency and reliability of the casting operation.

This paper investigates the importance of dynamic process monitoring by means of a continuous temperature measurement system in the tundish and its direct impact on the properties of the final product.

Brief information about Kardemir® and Activities

Kardemir® was established in Karabük on 3 April 1937 as Turkey's first heavy industry factory. Founded on the instructions of Mustafa Kemal Atatürk, the factory played a key role in Turkey's industrialisation process. Initially operating under Sümerbank, Kardemir® became an independent state-owned enterprise (SOE) in 1955. Kardemir®, which developed over the years, was privatised in 1995 and renamed Karabük Demir-Çelik Sanayi ve Ticaret AŞ.

Kardemir® has made significant contributions to Turkey's industrial sector and pioneered the establishment of large industrial facilities such as Erdemir and İsdemir. With a crude steel production capacity of 2,600,000 tonnes/year, Kardemir® has a wide range of products such as railway rails, high-speed train rails and various steel profiles. As a strategic business partner especially for the railway sector, Kardemir® is the only producer in the region and its products are also recognised in the international market.

Kardemir®, which renewed itself with technological investments after privatisation, increased its productivity with modern production techniques and rose to an exporting position. Thanks to investments such as the Rail and Profile Rolling Mill, Bar and Coil Rolling Mill, Kardemir® has expanded its product range and assumed a critical role in the railway mobilisation in Turkey. Kardemir® is also active in the energy sector and has undertaken important projects such as the Gas Fired Power Plant. In addition, Kardemir® ranked 26th in the latest 'Turkey's Top 500 Industrial Enterprises' 2019 report announced by the Istanbul Chamber of Industry.

Within the scope of corporate social responsibility projects, Kardemir® invested in Karabük University and started scholarship activities in 2020. The company, which employs approximately 5,000 people, continues to grow with its industrial culture and corporate governance experience and is rapidly progressing towards its sustainability goals. Kardemir® maintains its leadership in the sector as one of the largest industrial enterprises in Turkey.

Figure 3. Karabuk Iron and Steel Plant (Kardemir®).

CasTemp SuperHeat (SH) System

The continuous and reliable measurement of liquid steel temperature, a critical process parameter during mold casting of liquid steel, significantly influences the casting process and the final product quality. At Heraeus Electro-Nite, the development and sustainable utilization of the CasTemp system, enabling dynamic temperature control in continuous casting processes, along with the integrated liquidus measurement and superheat control system (CasTip), have become a primary focus. Emphasizing continuous innovation, Heraeus Electro-Nite facilitates not only the continuous measurement of liquid steel temperature in the continuous casting process but also enables superheat control through the developed liquidus measurement sensor. The CasTip system performs liquidus measurement by using a submersible probe to extract a liquid steel sample into its chamber, and through specialized sensors, it measures the thermal solidification temperature via the phase diagram. The system works in conjunction with the CasTemp system and employs the measured critical temperature, determined by the company, to create a model after the liquidus measurement. Utilizing his model, the system proactively alerts the operator to prevent tundish cooling. Furthermore, by ensuring accurate liquidus measurement and continuous temperature monitoring, the system effectively manages ladle furnace exit temperatures, enabling operation within the desired critical temperature range and providing the capability for controlled operation at maximum speed.

Using existing technologies, the liquid steel temperature within the tundish is periodically measured by operators through the utilization of disposable thermocouples based on the immersion temperature measurement principle (Figure 4a and Figure 4b). The measurement duration, dependent on the response time of the thermocouple, lasts between 4 to 6 seconds. During this period, the operator must maintain the measurement lance in close proximity to the liquid steel without moving it. In facilities with integrated CasTemp systems, a refractory-coated sensor is placed within a crucible integrated into the tundish body, allowing for longlasting temperature measurement within the tundish. This product, installed by the refractory team, enables the measurement of liquid steel temperature throughout a service cycle of the tundish (Figure 4c). The device image of the castemp system, which is an online temperature measurement system in the tundish, and the castip liquidus measurement sensor are shown in figure 5.

Figure 4. Standard temperature measurement practice (a & b), CasTemp measurement practice (c).

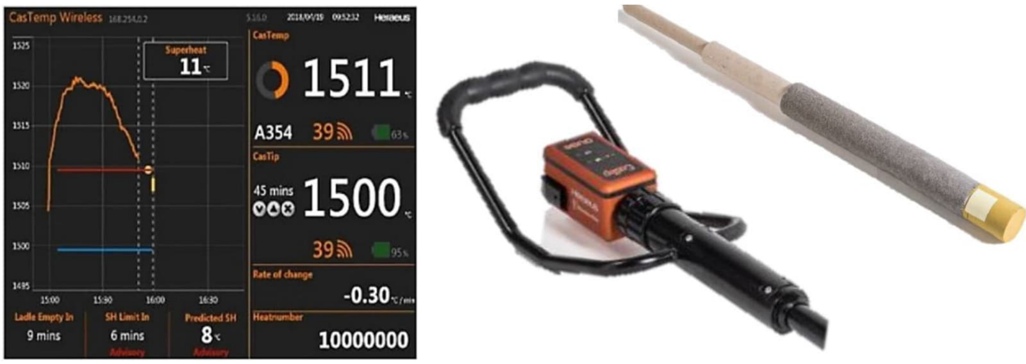

Figure 5. CasTemp SH dashboard and Liquidus measurement sensors.

PRACTICAL SITE STUDIES

Castemp system assembly starts with the control of the location of the tundish in the continuous casting machine. Then, after determining the place where the castemp system will be mounted on the tundish, drilling operations are carried out. After the hole is drilled, the surfaces are levelled. The surfaces must be smooth during assembly. Well Block slot is opened by drilling from the centre and edges of the hole. After the holes on the tundish surface are prepared, the application set is assembled. Then the well block and castemp probe are mounted with the relevant mortars. It is one of the most important criteria to comply with occupational safety rules while performing all these assembly operations. Figure 6 shows the images taken at Kardemir® site during the CasTemp system installation.

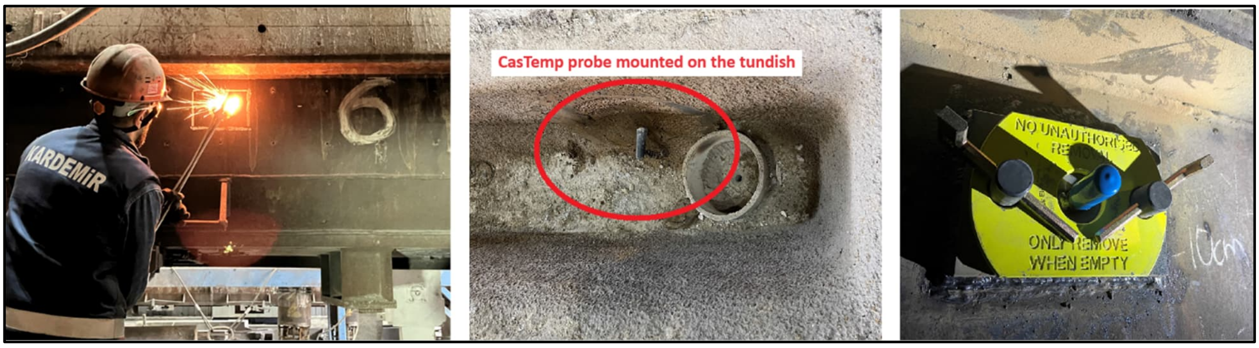

Figure 6. CasTemp continuous temperature measurement system installation applications at Kardemir® field.

DYNAMIC CASTING TEMPERATURE CONTROL

This study was conducted by selecting two different grades and two tundishes within each grade. The grades were designated as Grade A and Grade B, while the tundishes were labeled TD1 and TD2. The focus of the study is on temperature control within the tundish and the control of ladle furnace exit temperatures, achieved through the use of the CasTemp system across different grades and tundishes. By analyzing the performance of the CasTemp system in these varying conditions, the study aims to evaluate the effectiveness of temperature management in ensuring process stability and quality in steel production.

- **Grade A TD1**

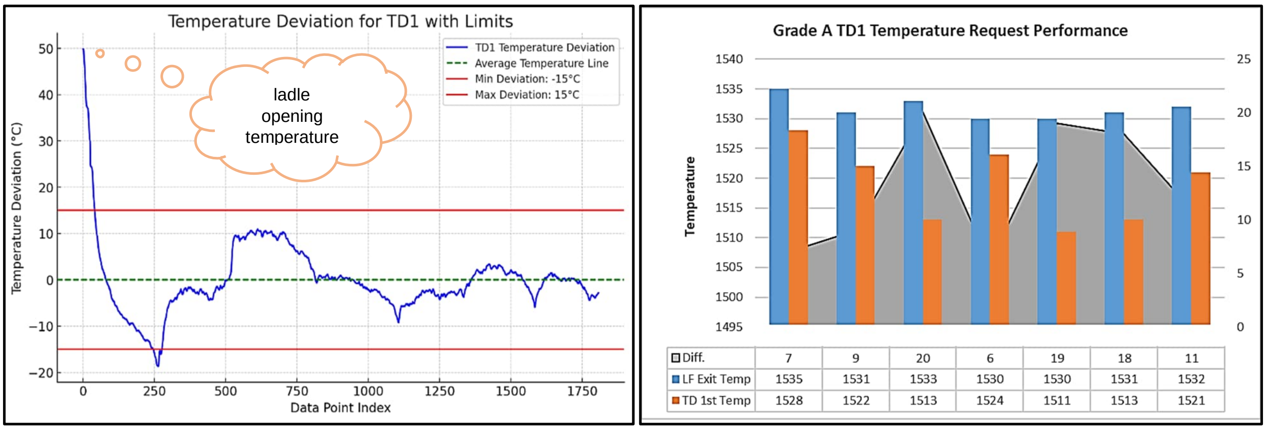

Figure 7: Temperature deviation with limits and LF Exit Temperature & TD (tundish) 1st Temperature with differences for Grade A TD1.

The temperature deviations for Grade A TD1 were well-controlled, with approximately 96.0% of the readings falling within the ±15°C range around the average temperature. This high level of consistency highlights the effectiveness of temperature management in TD1 for Grade A.

The temperature request performance, comparing LF Exit temperatures to TD 1st temperatures, showed that the temperature differences ranged between 6°C and 20°C, with an average difference of approximately 13°C. This indicates a strong alignment between operator requests and actual temperatures achieved, with minor deviations that are well within acceptable limits.

- **Grade A TD2**

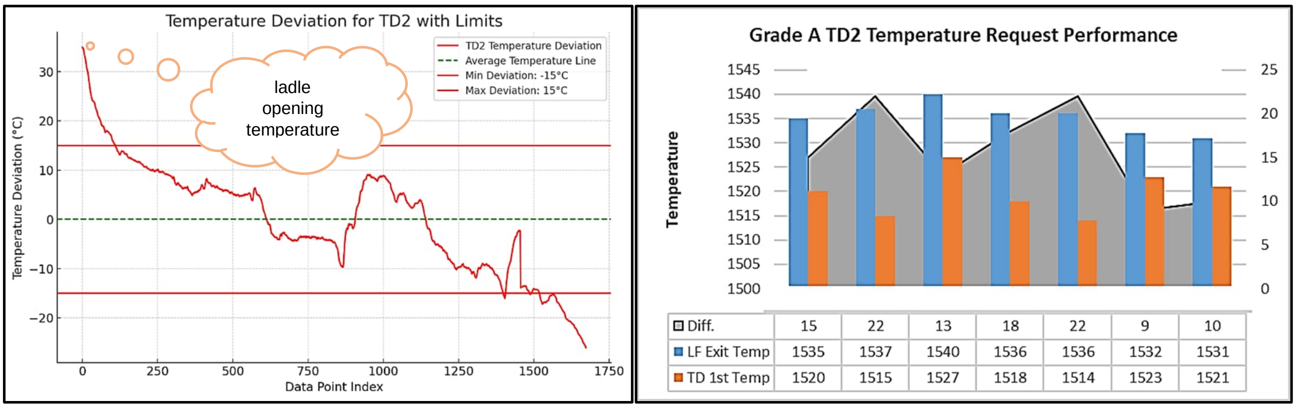

Figure 8: Temperature deviation with limits and LF Exit Temperature & TD 1st Temperature with differences for Grade A TD2.

In Grade A TD2, 77.2% of the temperature readings were within the ±15°C deviation range, reflecting reasonable but less consistent control compared to TD1.

The temperature request performance for TD2 showed differences between LF Exit and TD 1st temperatures ranging from 9°C to 22°C, with an average difference of 16°C. Although the process remains largely stable, the variability suggests that there may be occasional challenges in achieving the precise temperatures requested.

- **Grade B TD1**

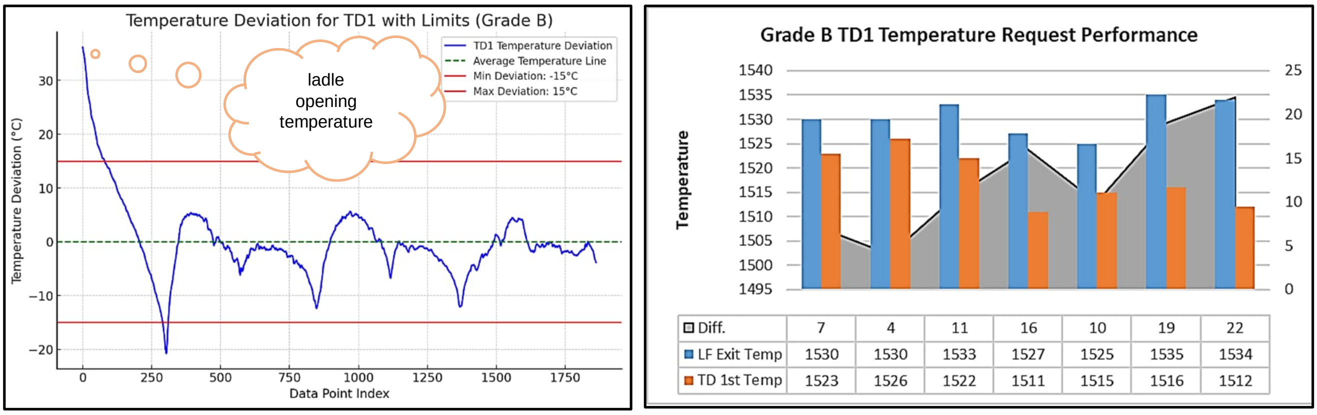

Figure 9: Temperature deviation with limits and LF Exit Temperature & TD 1st Temperature with differences for Grade B TD1.

Grade B TD1 displayed a strong temperature deviation performance, with 94.6% of the readings within the ±15°C range, similar to the performance seen in Grade A TD1. This indicates a robust temperature control process in place.

The temperature request performance for TD1 in Grade B revealed that the differences between LF Exit and TD 1st temperatures ranged from 4°C to 22°C, with an average difference of 13°C. This consistency demonstrates effective operator control in achieving the desired temperature conditions.

- **Grade B TD2**

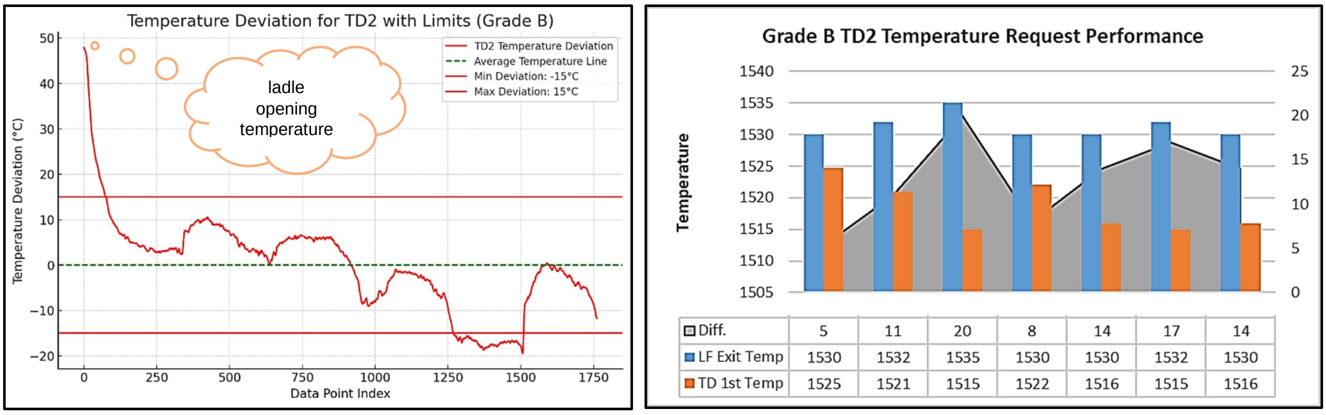

Figure 10: Temperature deviation with limits and LF Exit Temperature & TD 1st Temperature with differences for Grade B TD2.

For Grade B TD2, 77.6% of the temperature readings fell within the ±15°C deviation range, mirroring the performance seen in Grade A TD2. This suggests a similar level of variability and potential areas for improvement.

The temperature request performance in TD2 for Grade B showed differences ranging from 5°C to 20°C, with an average difference of 13°C. This greater variability underscores the need for closer monitoring and adjustment to ensure that the temperature requests are met more precisely.

Across both Grade A and Grade B, TD1 consistently outperforms TD2 in maintaining the desired temperature ranges and in minimizing deviations from the target. The smaller temperature differences between LF Exit and TD 1st temperatures in TD1 further emphasize its superior control. The comparison between Grade A and Grade B indicates that while both grades generally maintain effective temperature control, TD2 in both grades shows greater fluctuations. The consistency in these findings suggests that targeted improvements in the TD2 process could lead to more uniform and reliable temperature management across all operations.

CONCLUSIONS

Final Process And Product Assesments

- **Casting Performance Indicators**

1. Casting Speed

With continuous temperature monitoring in the tundish, process control is realised at a more optimum level. In this way, it is clearly seen in the graph down that the casting speed is successful at the targeted levels. Successful casting speed at targeted levels increases productivity, improves product quality, saves energy, reduces costs, ensures production stability and gains competitive advantage. In this way, the production process becomes more efficient and profitable (Figure 12).

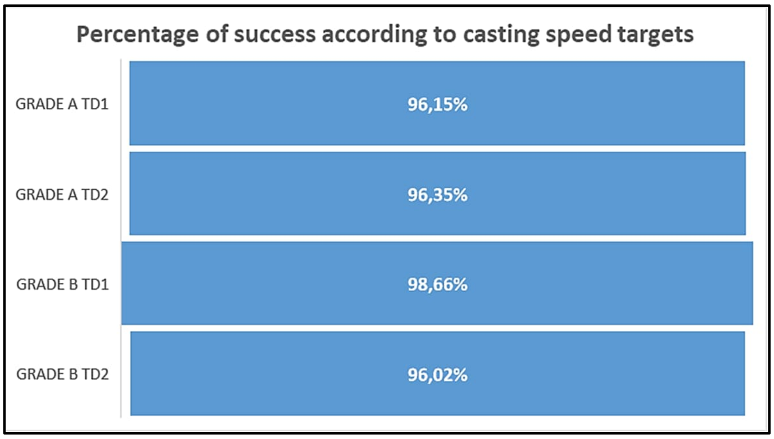

Figure 11: Percentage of success according to casting speed targets.

2. Tundish Level Control

There is a deviation of 1% in the tundish ladle overlaps due to the falling level. Thanks to the Castemp system, temperature changes can be dynamically detected and 99% success has been achieved in tundish level control. Tundish level is stabilised. This ensures stable casting conditions and maintains the process-product quality balance.

3. Casting Yield

Casting yield is a measure of how much of the raw material input is produced as a final product. High casting efficiency means that the same amount of product is obtained with less raw material and energy consumption. This both reduces costs and increases sustainability. With the CasTemp system, the yield is successfully optimised by dynamically monitoring the temperature. In this way, raw material losses and defective casting rates are minimised (Figure 12).

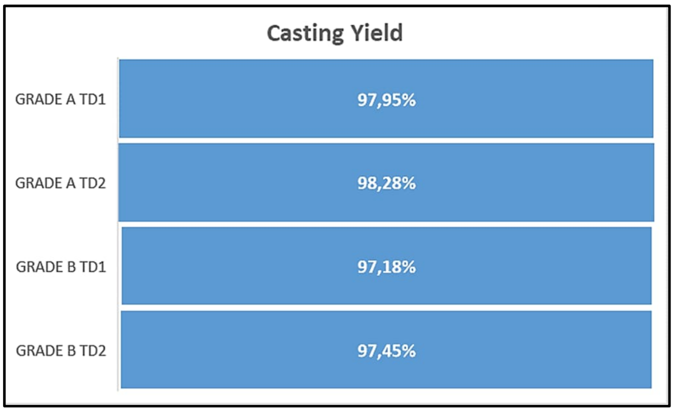

Figure 12: Percentage of casting yield.

4. Strand Loss

Since the process equipment and heat transfer in the process are provided perfectly by the company with appropriate practices, there were no road losses in Grade A and Grade B grades. Avoiding strand losses contributes to more efficient, economical and environmentally friendly production.

5. **Target Heat Ratio Of Final Product Spesification (Billet macrographs)**

The CasTemp online temperature measuring system is used to improve billet quality and optimise the continuous casting process. The billet macrographs shown in Figure 13 are given as two different castings for low superheat and high superheat. Corner cracking and bulging occurred on the surface of the billet when casting high superheat caused by high temperature. The surface of the billet cast with low superheat showed sharp lines and no surface defects were observed. With the Castemp dynamic temperature measuring system, the temperature in the tundish can be monitored every 15 seconds and high superheat situations can be avoided. High overheating causes the billet to have an uneven surface and causes problems in subsequent processing (e.g. rolling or cutting). This adversely affects the mechanical properties of the product.

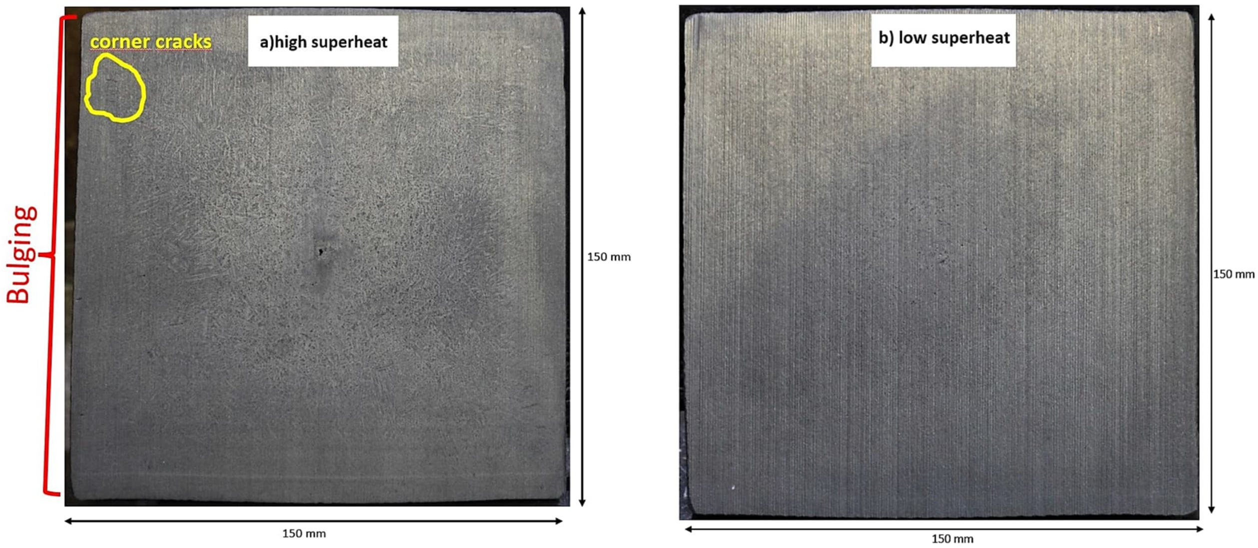

Figure 13: a)high superheat casting, b)low superheat casting.

FUTURE STUDIES

Following this study, the next phase will focus on the more effective management of ladle exit temperatures and the stable control of tundish temperatures. Additionally, future research will aim to integrate **advanced steel cleanliness** processes (such as the control of nitrogen, hydrogen, and oxygen pick-up) and **secondary cooling integration.**

ACKNOWLEDGMENTS

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REFERENCES

[1] Ji, Z., Yang J., Online Dynamic Control of Secondary Cooling for the Continuous Casting Process, 269-272 (2010), 269

[2] Jiaocheng, M., Applying of Real-time Heat Transfer and Solidification Model on the Dynamic Control System of Billet Continuous Casting, 1722–1727(2008), 1726

[3] Louhenkilpi,S., Chapter 1.8 Continuous Casting of Steel, 373-434 (2013), 375

[3] Thomas, B., Continuous Casting of Steel, 1–56 (2001), 10

[4] Vynnycky, M., Continuous Casting, 1-3 (2019), 2

[5] https://worldsteel.org/data/

[6] https://www.cemilbelder.com

[7] https://www.capital.com.tr