Investigation of Camber and Shifting in Thin Slab Casting of Steel: Analysis of Process Parameters

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Abstract - *This paper focuses on the investigation of camber and shifting of slabs in the thin slab casting process of steel. The study begins with a tracking process to monitor the camber of slabs based on their unique slab IDs. Subsequently, data analysis is conducted to examine the relationship between camber and various process parameters. The findings reveal that wedge formation is a significant factor contributing to camber in the thin slab casting process. Further analysis identifies segment water force as the primary cause of the wedge formation. As a result, the study proposes the monitoring of segment force to mitigate camber and shifting issues in thin slab casting. By understanding the underlying causes and implementing appropriate monitoring techniques, this research aims to improve the overall quality and efficiency of the thin slab casting process in the steel industry.*

***Key Words*: Quality, Camber, Data, Tracking, Wedge**

1. INTRODUCTION

The thin slab casting process plays a crucial role in the production of high- quality steel. However, the occurrence of camber and shifting in the cast slabs poses significant challenges to the industry. Camber refers to the curvature or bowing of the slab, while shifting refers to the lateral displacement of the slab during the casting process. These defects not only affect the dimensional accuracy of the slabs but also lead to downstream processing difficulties and reduced product quality. To address these issues, this paper presents a comprehensive investigation into the causes of camber and shifting in thin slab casting of steel. The study begins by implementing a tracking process to monitor the camber of individual slabs based on their unique slab IDs. This enables the collection of data on Camber variations throughout the casting process. Subsequently, a detailed analysis of the collected data is performed to identify the key process parameters that influence camber and shifting. The study reveals that wedge formation is one of the primary factors contributing to camber in thin slab casting. Further analysis delves into the underlying causes of the wedge formation, leading to the discovery that segment water force plays a significant role. Based on these findings, the paper proposes the monitoring of segment force to mitigate camber and shifting issues in thin slab casting. By closely monitoring and controlling the segment water force, it is possible to minimize the formation of wedges and subsequently reduce camber and shifting defects.

The objective of this research is to enhance the overall quality and efficiency of the thin slab casting process in the steel industry. By gaining a deeper understanding of the causes of camber and shifting and implementing effective monitoring techniques, manufacturers can optimize their processes, improve product quality, and reduce costly rework and scrap. In the following sections, this paper will delve into the methodology employed for tracking camber, the data analysis techniques used to identify the influence of process parameters, and the findings related to wedge formation and segment water force. The proposed approach for monitoring segment force and its potential impact on reducing camber and shifting defects will also be discussed. Finally, the paper will conclude with recommendations for future research and practical implications for the steel industry.

2. LITERATURE REVIEW

The section of this paper provides a comprehensive overview of the existing research and knowledge related to camber and shifting in thin slab casting of steel. Previous studies have identified camber and shifting as common defects in the thin slab casting process, which can have detrimental effects on product quality and downstream processing. The review highlights the use of tracking processes to monitor camber variations throughout the casting process, enabling researchers to collect valuable data on camber behavior. Furthermore, the literature review delves into the analysis of various process parameters that influence camber formation, such as casting speed, cooling water flow rate, and Mold design. These investigations aim to identify the key factors that contribute to camber and shifting defects, providing insights into potential areas for process optimization.

In addition to process parameters, the literature review explores the role of wedge formation as a significant factor contributing to camber defects. Wedges, formed between the slab and the Mold, disrupt the uniform cooling process and lead to uneven stress distribution, resulting in camber formation. The review highlights studies that have investigated the mechanisms of wedge formation and its relationship with camber defects. This understanding of wedge formation provides valuable insights into the underlying causes of camber and shifting, paving the way for targeted mitigation strategies. Moreover, the literature review focuses on the influence of segment water force on wedge formation and subsequent camber defects. Segment water force refers to the force exerted by the cooling water on the slab segments during the casting process. High segment water force can lead to uneven cooling, resulting in the formation of wedges and subsequent camber defects. The review discusses studies that have explored the relationship between segment water force, wedge formation, and camber defects. This knowledge is crucial for developing effective strategies to control and optimize segment water force, thereby reducing camber and shifting in thin slab casting.

Lastly, the proposed strategy of monitoring segment force to mitigate camber and shifting defects. By closely monitoring the segment water force and adjusting it as needed, manufacturers can minimize wedge formation and reduce camber. The review discusses studies that have implemented segment force monitoring techniques and evaluates their effectiveness in reducing camber and shifting defects.
By synthesizing the existing research, the literature review sets the stage for the current study, identifying gaps in knowledge and providing a foundation for the methodology and findings presented in the paper. It emphasizes the importance of understanding the factors influencing camber and shifting in thin slab casting and the potential for targeted process optimization and monitoring techniques to mitigate these defects.

3. METHODOLOGY

3.1 Tracking Process for Camber Analysis:

1. Division of Slab: The slab is divided into three sections - head, body, and tail - based -on its length. This division allows for a more detailed analysis of camber at different parts of the slab.

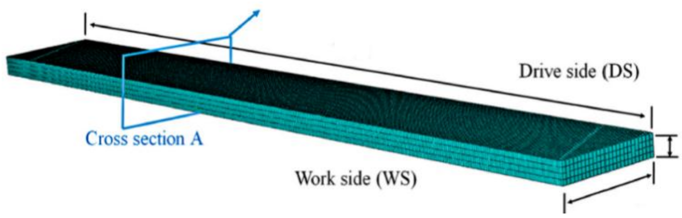
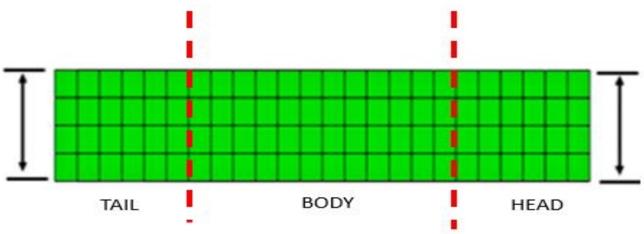


Fig 1: Division of Slab



2. Sensor Data Collection: Sensors installed in the heating furnace are utilized to collect real-time camber values of the slab. These sensors provide accurate measurements of camber, enabling precise analysis.

3. Linking Camber Data with Slab ID: To enhance understanding and facilitate further analysis, the camber data is linked with the corresponding Slab ID. This association enables the tracking and examination of camber data for individual slabs, leading to more targeted optimization efforts. By implementing this methodology, a comprehensive and systematic approach to camber analysis is achieved. The division of the slab into sections, coupled with sensor data collection and the linkage of camber data with Slab ID, allows for a thorough understanding of camber behavior. This knowledge can then be leveraged to optimize the thin slab casting process, resulting in improved efficiency and quality.

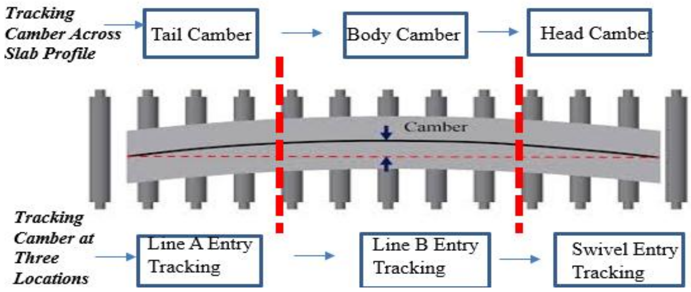


Fig 2: Top View Slab showing Camber.

The Fig:2 illustrates a method for tracking camber across a slab profile. It shows a segmented slab with camber represented by a curved line. The tracking process begins by assessing the "Head Camber," followed by the "Body Camber," and finally the "Tail Camber," progressing across the slab. Additionally, the camber is tracked at three specific locations: the "Line A Entry," "Line B Entry," and "Swivel Entry," providing a comprehensive analysis of the camber across the entire slab profile.

The overall camber (the combined curvature across the entire slab's length) is classified into different severity levels based on the total deviation from the ideal centerline:

A.) Low Severity Camber: Total camber between 50 mm and 80 mm.

B.) High Severity Camber-2: Total camber greater than 80 mm.

C.) High Severity Camber-1: Total camber greater than 100 mm.

3.2 Data Analysis for Camber & Process Parameter:

Box plot shows the distribution of overall slab camber for two different lines (Line A and Line B) in TSCR process. The box plot reveals that Line B produces slabs with significantly higher median camber and greater variability than Line A. Line A shows lower camber values with a smaller range, although several high positive camber outliers suggest inconsistencies. In contrast, Line B displays a wider distribution of camber values, centered around a much higher median, and includes a high positive outlier, indicating potential process control issues on that line.

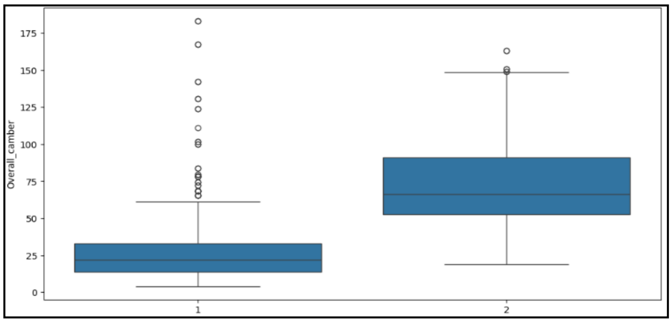


Fig 3: Box plot showing variation in Line A and B

A bar chart ranks the importance of process parameters and slab characteristics in determining final camber. Further analysis, using a drill-down approach, identified the root cause of the camber issue.

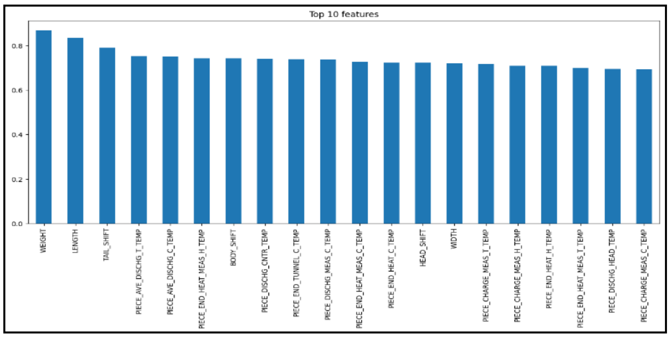


Fig 4: Feature Importance in relation to Overall Camber

4. RESULT & DISCUSSION:

4.1 Identification of Wedge Formation as a Cause of Camber:

The data presented in the Fig:5 provides compelling evidence for the hypothesis that wedge formation is a significant contributor to camber. The figure depicts boxplots representing the distribution of common-section camber values for different Slab Wedge measurements.

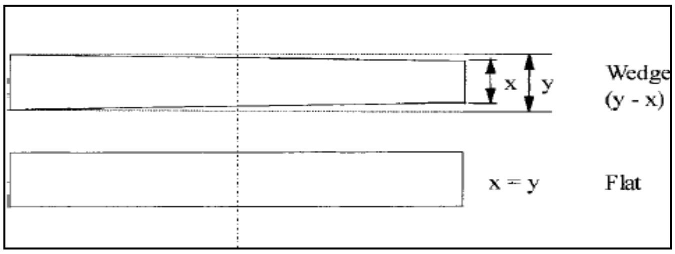


Fig 5: Definition of Slab wedge

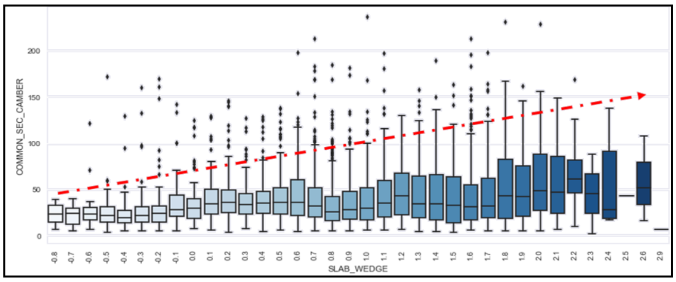


Fig 6: Relation of Camber with Slab Wedge

As the Slab Wedge values increase, we observe a clear positive trend in the median Camber values. This positive trend is further emphasized by the red dashed line, indicating a linear regression fit. The increasing values of Camber with increasing Slab Wedge strongly suggest a direct relationship between wedge formation and the development of camber. The boxplots also reveal a widening of the interquartile range (IQR) as the Slab Wedge increases.

This implies that the variability in camber values becomes larger with more significant wedge formation. The presence of outliers (represented by black dots) further supports the idea that wedge formation introduces significant variability into the camber measurements.

4.2 Investigation of Segment Water Force as the Main Cause of Wedge Formation:

The investigation of caster segment water force as the main cause of wedge in slab in thin slab casting is an important area of research in the field of metallurgy and casting technology. The wedge defect refers to the formation of a triangular-shaped gap or depression in the slab during the casting process. This defect can have significant implications on the quality and integrity of the final product. The caster segment water force refers to the water flow and pressure applied to the mold during casting. It has been observed that excessive water force can lead to uneven cooling and solidification of the slab, resulting in the formation of wedges. Understanding the factors influencing the water force and its impact on wedge formation is crucial for developing effective control measures and optimizing the casting process to minimize defects and improve product quality

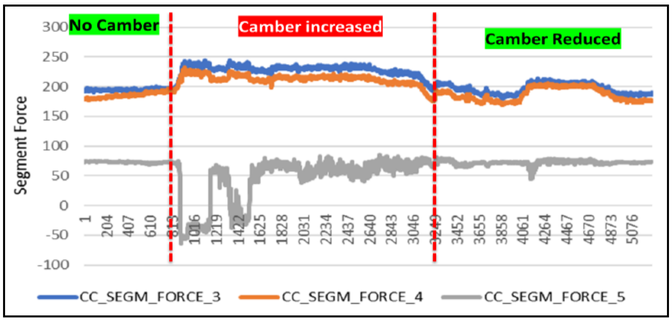


Fig 7: Segment Force 3,4&5 of Caster showing deviation when camber is high and low.

4.3 Relation with Casting Speed

The graph suggests a relationship:

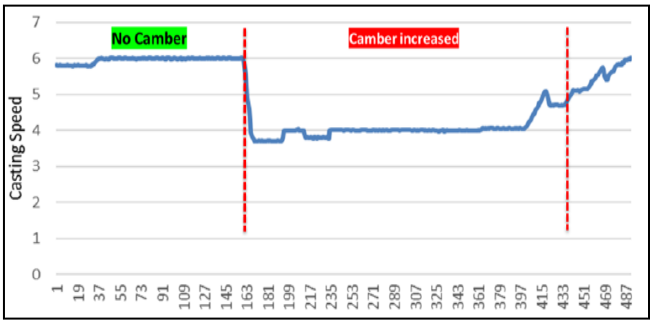


Fig 8: Casting Speed is also showing deviation when camber occurred.

- **Initial Phase (No Camber):** The graph shows a relatively constant, high casting speed initially. This suggests stable casting conditions where the slab is forming uniformly, resulting in minimal camber.

- **Camber Development:** The significant drop in casting speed, indicated by the red dashed lines, is directly followed by an increase in camber. This implies that the speed reduction causes a disturbance in the solidification and cooling process of the slab.

The reduced casting speed likely leads to increased heat transfer from the molten metal to the mold or rolls. This can cause:

- **Uneven cooling:** Slower speed allows more time for heat dissipation, potentially leading to faster cooling and higher solidification rates in certain areas of the slab compared to others. This unequal cooling is a primary cause of camber.

- **Differential shrinkage:** Uneven cooling results in different degrees of shrinkage across the slab's width. The areas that cool faster and solidify earlier contract more, resulting in the curved shape – camber.

- **Stress build-up:** Differential shrinkage and cooling creates internal stresses within the solidifying metal. These stresses can contribute to warping and the development of camber.

- **Subsequent Speed Changes:** The graph shows the casting speed fluctuating after the initial drop and before the second drop. This suggests that while the initial speed change was the most significant factor contributing to camber, further variations in casting speed can exacerbate or modify the effect. For example, slightly increased speed after the first drop may slightly reduce camber or alter the overall shape of the curvature before further speed reduction leads to further camber.

4.5 Relation with Back Pressure:

The figure shows the back pressure in Thin Slab Casting Rolling (TSCR) for casting. The red dashed lines indicate the points where camber (a curvature in the slab) is observed. The key observation is that the back pressure exhibits a distinct variation around the time camber is observed. This suggests a strong correlation between back pressure fluctuations and camber formation.

- **Before camber:** In most cases, the back pressure shows a relatively stable or gradually changing trend. This implies a consistent flow of material and relatively uniform pressure distribution within the caster.

- **During camber formation:** The back pressure undergoes a significant change. This could manifest as a sudden drop (as in some plots), a temporary increase, or a more complex fluctuation. This variation suggests that the flow of material within the caster becomes disrupted, leading to uneven solidification and consequently, the development of camber.

- **After camber:** Once the camber is formed, the back pressure may return to a more stable state, although it's not always a perfect return to the pre-camber level.

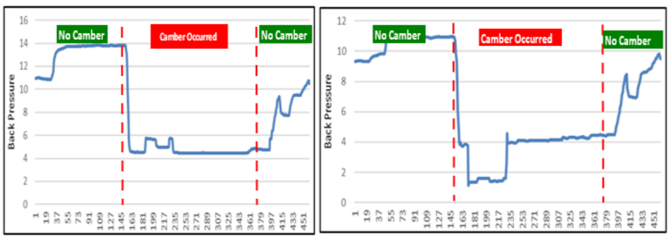
The observed back pressure variations likely reflect changes in the molten metal flow within the caster, caused by factors such as:

- **Uneven cooling:** If some parts of the slab cool faster than others, this could create variations in the solidifying metal's flow resistance, influencing the back pressure.

- **Meniscus fluctuations:** Changes in the meniscus (the liquid-gas interface at the top of the molten metal pool) could alter the pressure distribution within the caster.

- **Mold clogging or imperfections:** Any blockages or irregularities in the mold can restrict flow, generating localized pressure changes.

- **Solidification variations:** Changes in the solidification rate of the slab, potentially due to temperature fluctuations or compositional variations in the molten metal, could affect flow patterns and pressure.



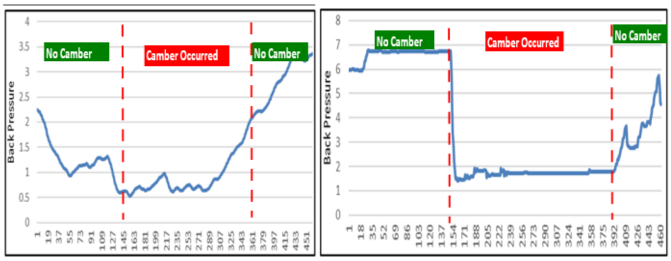


Fig 9: Back Pressure of Caster showing deviation during camber formation.

4. CONCLUSION:

It is extremely difficult to quantify the amount of camber generated by these effects on a slab-by-slab basis. However, they can be controlled by establishing tight engineering standards for equipment and maintenance procedures. The goal is to develop an automatic camber control system which predicts and minimizes camber for a wide range of varying operating and processing parameters.

REFERENCES

[1] M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989. Xu, Dong, Yang Liu, Xiaochen Wang, Quan Yang, Zhengyang Dai, and Xiaodong Wang. "Research and application on slab camber control model in hot rolling." Ironmaking & Steelmaking (2020).

[2] Biggs, D. L., S. J. Hardy, and K. J. Brown. "Influence of process variables on development of camber during hot rolling of strip steel." Ironmaking & Steelmaking 27, no. 1 (2000): 55-62.

[3] Keats, J. Bert, and Douglas C. Montgomery. "Statistical process control in manufacturing." (No Title) (1991).