CONTRACTION PHENOMENON OF PERITHETIC STEELS IN CONTINUOUS SLAB CASTING

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1. INTRODUTION

The continuous casting process can be described as a heat extraction reactor, where liquid steel is continuously transformed into a solid with dimensions defined by the mold (primary cooling), followed by the complete solidification of the remaining liquid steel along the machine (secondary cooling).

The solidification of steel occurs from the outside in, starting with the formation of a thin shell in the mold through indirect cooling. This initial shell must be able to withstand the ferrostatic pressure as it exits the mold. From this point, direct cooling begins, where water (or a mixture of air and water) is applied to the surface of the solidified shell. As the shell becomes thicker, the heat transfer rate progressively decreases along the machine, as the heat extraction from the remaining liquid steel inside the slab is mainly governed by the thermal conduction of the growing shell, which represents an increasingly robust physical barrier to heat transfer.

This brief description is necessary because the phenomenon addressed in this work is based on the balance between the contraction and expansion forces present in the process. Contraction is inherent to the steel solidification process, evidenced by the density change associated with the transformation of liquid steel into solid, varying from approximately 7.0 g/cm³ to 7.85 g/cm³. On the other hand, the expansion force is also intrinsic to the process, attributed to the ferrostatic pressure of the remaining liquid steel. This force increases with the height of the steel column, being lower at the meniscus of the mold and higher at the end of the vertical-curved part of the machine.

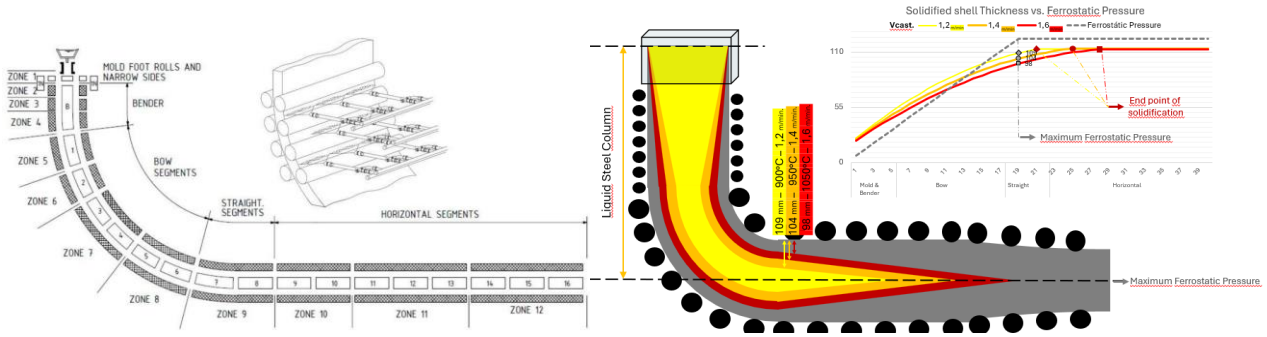


Figure 01: Representation of the zones of a continuous casting machine and real data obtained in a solidification process, where the difference in shell thickness and temperature at the same point can be observed.

The effect of slab width variation during solidification in a continuous casting machine is called broadening. This phenomenon results from the relationship between contraction and expansion forces, i.e., the balance between the mechanical resistance forces of the solidifying shell (thickness and temperature gradient) and the increasing ferrostatic

pressure, defining the magnitude of the dimensional width variation, operationally referred to as the contraction factor.

In the mold, the width variation is negative, as per the typical solidification regime of steel; therefore, a taper is applied to compensate for this contraction and maintain contact between the mold plate and the surface of the solidifying steel shell. After the formation of the initial solid shell, the steel can still undergo phase transformations, as in the case of peritectic steels, which occurs in two main stages:

1. First solidified phase: Initially, the δ-ferrite (delta ferrite) phase with a body-centered cubic (BCC) crystalline structure forms from the liquid steel.
2. Phase transformation with cooling: As cooling continues, the peritectic transformation occurs, where δ-ferrite reacts with the remaining liquid to form austenite (γ) with a face-centered cubic (FCC) structure. This transformation is accompanied by a significant volumetric change.

After exiting the mold, the broadening phenomenon proper begins, where the resistance of the solidifying shell defines the magnitude of the width variation. The shell resistance is a complex function of the steel's chemical composition, solidification structure/phase, second-phase precipitates, temperature, and shell thickness, which varies depending on the casting speed, secondary cooling intensity, and final solidification point.

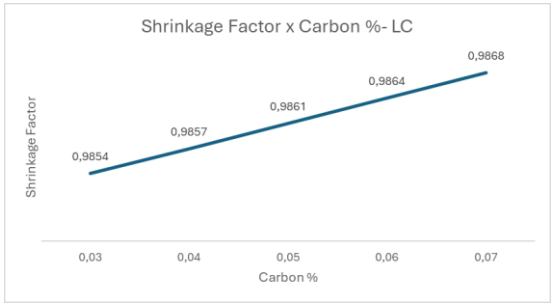
2. DEVELOPMENT

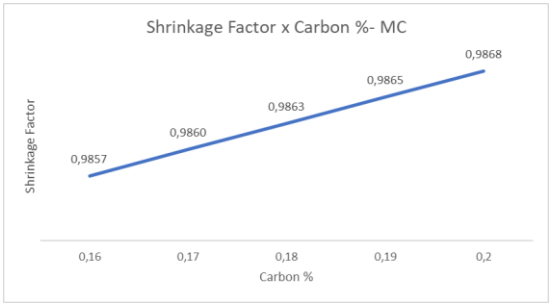
As already mentioned, the chemical composition of the steel is decisive in the mechanical resistance of the shell in the contraction (or expansion) mechanism during continuous casting. In general, the higher the alloy content of the steel, indicated by a greater carbon equivalent, the greater the mechanical resistance of the shell relative to the ferrostatic pressure. Based on this principle, equations were developed to define the shrinkage factor used to determine the mold bottom width necessary to achieve the nominal slab width within the customer's specified tolerances. Essentially, the equation considers the following process assumptions:

1. The higher the carbon equivalent of the steel, the greater the mold bottom width.
2. The higher the casting speed, the smaller the mold bottom width.
3. The greater the volume of water used in primary and secondary cooling, the greater the mold bottom width.
4. The larger the mold taper, the wider the mold bottom width.

However, for the group of unalloyed peritectic steels, a different behavior was observed in assumption 1. For certain carbon values, the slab width measurements varied significantly from expectations, resulting in rework and metallic loss.

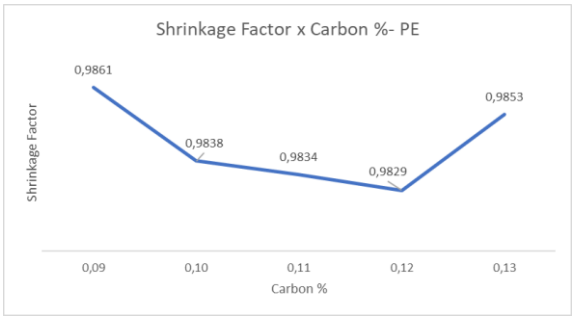
To demonstrate this result, the measurements of several slabs cast at a constant speed in non-alloy steel were filtered for different steel groups. As observed, for the low carbon (LC) and medium carbon (MC) steel groups, the shrinkage factor (mold bottom width / cold slab width) increases with the percentage of carbon. This follows the rule that a higher carbon equivalent leads to greater shell resistance to ferrostatic pressure.





Graphs 01 and 02: Behavior of the shrinkage factor versus the percentage of carbon in steel at a constant casting speed and other constant impact variables in medium carbon (MC) and low carbon (LC) steels.

However, as can be seen in graph 3 below, the contraction behavior does not follow this rule for unalloyed peritectic steels.



Graph 03: Behavior of the shrinkage factor vs % of steel carbon at casting speed and other constant impact variables in PE steels.

This phenomenon was explained during Brimacombe's training in the Mold Heat Transfer section. In summary, this study shows that irregular shell formation associated with deep oscillation marks in peritectic steels reduces heat transfer at the steel/mold interface. Consequently, the shell exits the mold thinner, making it less resistant to ferrostatic pressure and causing an "expansion" in the slab width, as there is no lateral support in the segments, only below the bender (edge roll). This study identified that the lowest heat transfer occurs in steel with 0.12% carbon.

The results of slab measurements in the AM Pecém continuous caster are consistent with this theory, as shown in graph 03. Before recognizing this phenomenon, the equation for the shrinkage factor of peritectic steel was similar to that of low and medium carbon steel, where the shrinkage factor increases with the percentage of carbon. For steel with 0.12% carbon, for example, the previous shrinkage factor for a casting speed of 1.4 m/min was 0.9877, and after adjustment, it is 0.9829. This difference in the shrinkage factor caused a 7 mm variation in a slab width of 1350 mm, leading to rework and metal loss due to excess width defects.

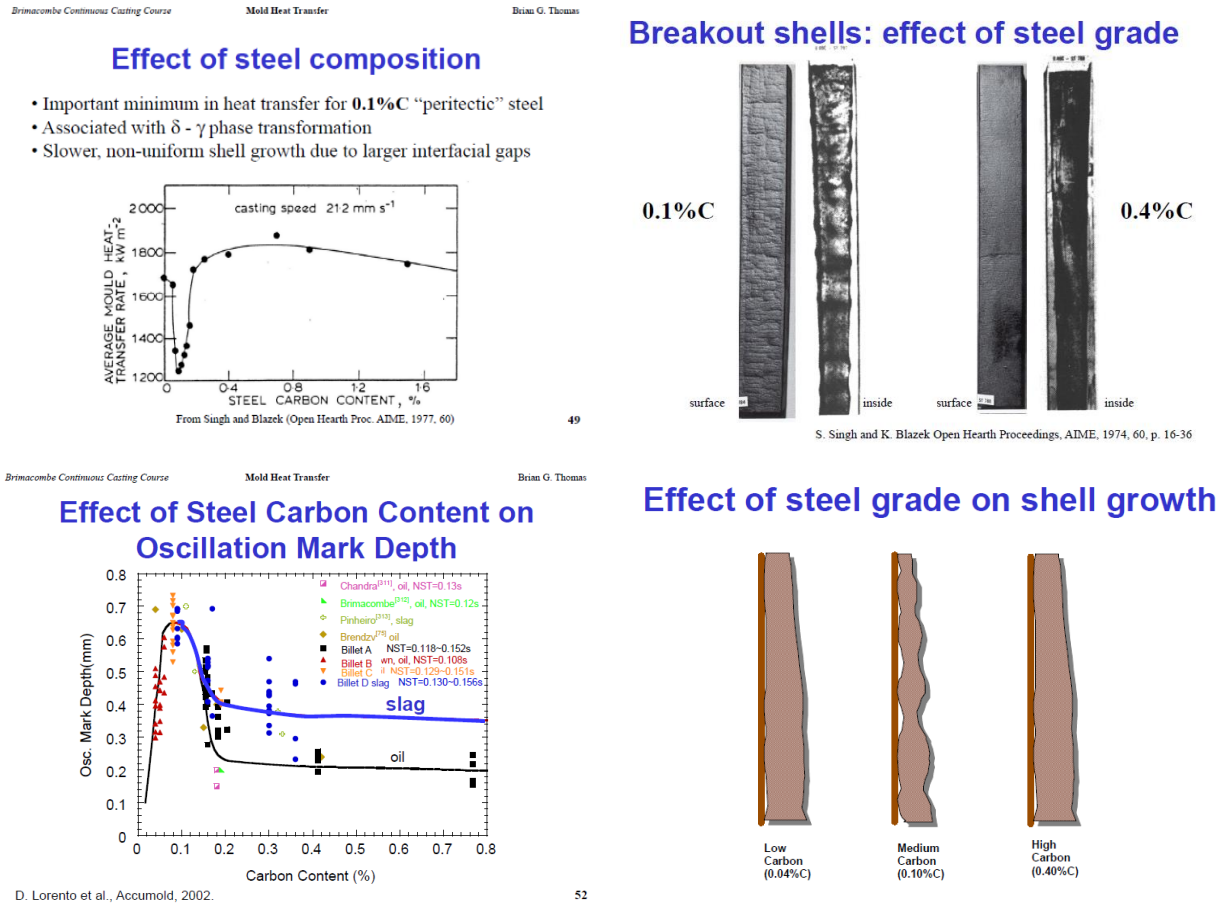


Figure 02: Mould heat transfer in peritectic steel according %C content

3. CONCLUSION

After understanding the peculiar behavior of heat extraction in the mold of peritectic steels according to the percentage of carbon, an adjustment was made to the shrinkage factor equation to reduce the variability of slab width, thereby minimizing rework and metallic losses.

This work of correlating the final slab width measurements with the peculiarities of heat transfer in the mold of peritectic steels with varying carbon percentages is innovative and has generated excellent benefits for AM Pecém by reducing rework and metal loss.

As the next steps, after installing the laser slab measurement and inspection system at the AM Pecém plant, the depth of the oscillation marks on the slabs will be measured to verify the graphs in figure 02 with actual measurements.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

1. Fu JianXun, Li Jingshe, Zhang Hui, Zhang Xingzhng, Mechanism of broadening of slab in the secondary cooling zone of continuous casting. SCIENCE CHINA-Technological Sciences. 54 (2011), No.5: 1228–1233
2. Fu JianXun, LI Jingshe, ZHANG Hui,. Effects of Width and Thickness of Sab on Broadening in Continuous Casting. Internacional Journal of Minerals, Metallurgy and Materials. 17 (2010), No. 6, 723.
3. Brimacombe Continuous Casting Course, Section O-13 e O-14, 2023, pp 50-54.