INFLUENCE OF CASTING SPEED ON CENTERLINE POROSITY FORMATION IN CONTINUOUSLY CAST ROUND STEEL BILLETS

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Abstract

During continuous casting of steel, a centerline porosity formation frequently occurs and participates on decrease of internal quality of continuously cast billets. To avoid the centerline porosity formation, a description of casting parameters connection with centerline porosity is necessary. This paper is focused on study of casting speed influence on centerline porosity formation in continuously cast round steel billets through a numerical modelling. Centerline porosity formation is closely related with solidification of billet which can be affected by casting speed change. Usually, in real conditions, the change of casting speed includes a change of cooling conditions both in primary and secondary zone. For determination of influence of technological parameter on observed quantitative parameters of billet, only casting speed was changed during numerical modelling while keeping cooling intensity. With relation of casting speed changes, the attention was paid also on metallurgical length which effects centerline porosity formation. Metallurgical length shortening should lead to reduction of centerline porosity formation. In accordance with literature knowledge, the increasing of fraction solid due to decreasing of casting speed was confirmed. Fraction solid increasing was caused by increase of time which billet spent in cooling zones. Mentioned fact affected positively metallurgical length shortening. Centerline porosity was evaluated by liquid pressure in centerline region of billet. The porosity formation can be assumed at zero liquid pressure in centerline region. It was found out that with decrease of casting speed, the liquid pressure in centerline region increased. Thus, occurrence of centerline porosity decreases with decrease of casting speed.

Keywords: Steel, continuous casting, numerical modelling, metallurgical length, centerline porosity

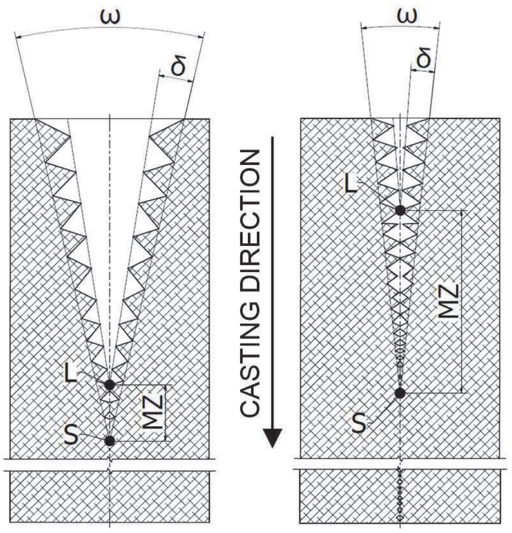
1. INTRODUCTION

Currently, over 2.5 thousand steel grades are casting by continuous casting technology. Universal setting of caster is impossible. Thus, during continuous casting, conditions leading to defects formation in billets can develop. These defects cause decrease of quality of billets and can participate on final products quality degradation. Particularly, in the case of internal defects which cannot be removed, their presence can lead to scrapping of the billet, eventually a final product. Internal unremovable defects include also centerline porosity. [1, 2]

The aim of this paper is numerical study of solidification of continuously cast round steel billets considering the centerline porosity formation. The relations between temperature field, metallurgical length and variable casting conditions will be described. Based on numerical model results, tendency to centerline porosity formation under various casting speed will be evaluated and a suitable adjustment of casting speed will be recommended with respect to billet high internal quality achievement.

Centerline porosity formation occurs in thermal axis region of billet when the supplementation of a melted steel in the final stage of solidification is interrupted - region MZ (two phase region) in **Figure 1**. MZ region is bounded by point L (liquidus) in top and by point S (solidus) in bottom. Between these points a mushy zone (two-phase region of solidification) is located. [3, 4]

Mushy zone included dendrite skeleton mesh which density increases with shortened distance from point S and with increase of fraction solid amount during solidification. [5] Between dendrites, capillary forces act and represent resistance to feeding of solidifying area in locations where the feeding by melted steel is necessary. If the capillary forces are bigger then feeding pressure, the supplementation of molten steel to solidifying area is interrupted and centerline porosity formation occurs due to shrinkage of steel. If we want healthy billet even in its thermal axis, it is necessary to ensure directed solidification (see **Figure 1a**). It means that solidification fronts progressing from billet surface should form an angle ω which reaches some critical value ω_{KR}. If $\omega < \omega_{KR}$, the MZ region and metallurgical length of billet extends and conditions for centerline porosity formation are getting better (**Figure 1b**).



a) b)

Figure 1 Solidification conditions a) for minimization of centerline porosity formation; b) supporting centerline porosity formation [3]

2. NUMERICAL MODELLING PROCEDURE AND SUMMARY OF SUGGESTED VARIANTS

Numerical modelling can be divided into three stages: 1. Preprocessing - input data preparation, thermodynamic properties of steel determination, computational mesh and geometry creation, numerical model definition; 2. Processing - computation; 3. Postprocessing - results evaluation etc. Detailed description of the whole procedure of numerical modelling of continuous casting, including thermodynamic properties determination, was stated in previous publications [6-10].

Table 1 Setting of suggested variants

Variant	Casting Temperature	Casting Speed
	(°C)	($m.min^{-1}$)
A	$t_L + 38$	v - 0.1
B	$t_L + 38$	v
C	$t_L + 38$	v + 0.1

With the aim of prediction of centerline porosity formation in continuously cast round steel billets, numerical simulations in computational software ProCAST was carried out. Billets temperature field was simulated using Thermal Module which is one of modules included in ProCAST software. Also, solidification of simulated variants was computed using Thermal Module. For prediction of centerline porosity formation, Advanced Porosity Module was chosen. [11]

To capture of influence of casting speed on centerline porosity formation, three variants of numerical simulations, for which only casting speed was changed, were computed. Other technological parameters as casting temperature, meniscus position etc., were set as constant as well as heat losses from billet. Setting of each suggested variant is shown in **Table 1**.

3. RESULTS AND DISCUSSION

3.1. Thermal Module results

In **Figure 2** the temperature field of simulated variants is shown. Billets surface temperature field evolving during casting with changing casting speed are plotted in **Figure 3**. As can be seen, the surface temperature decreases with decrease of casting speed.

Relating centerline porosity, metallurgical length and mushy zone were observed. **Figure 4** visualizes distribution of liquid core (metallurgical length) and solid fraction along the billets. **Figure 5** shows a metallurgical length dependence on casting speed. The metallurgical length increased with increasing casting speed.

Based on results of liquid and solid fraction distribution, length of mushy zone in thermal axis at the end of liquid core was measured. In case of mushy zone, increase of its length with increasing casting speed was found out (see **Figure 6**). Also, correlation between metallurgical length and mushy zone length was observed (**Figure 7**). With increasing metallurgical length, the mushy zone length was extended.

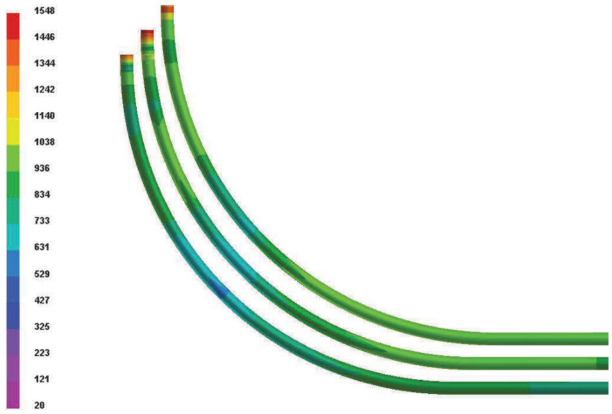


Figure 2 Billets temperature field (from left to right A, B, C)

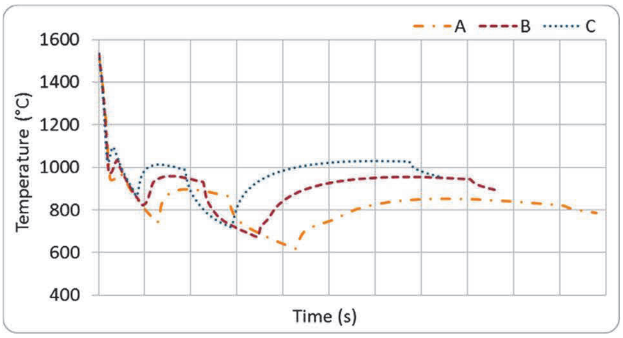


Figure 3 Billets temperature field evolution in dependence of casting time at different casting speeds

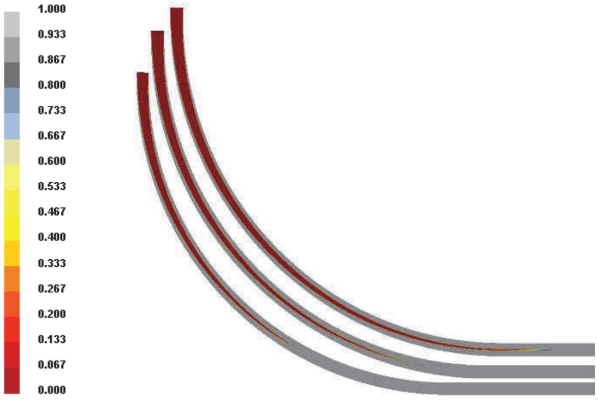


Figure 4 Billets metallurgical length (from left to right A, B, C)

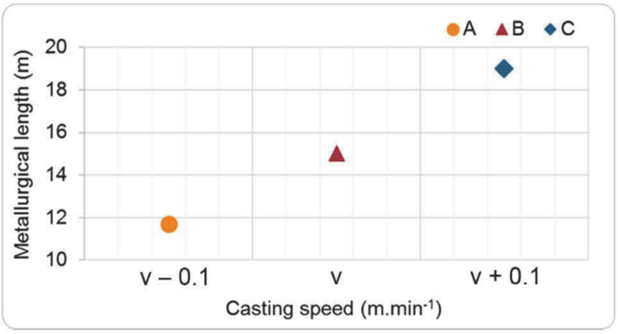


Figure 5 Metallurgical length dependence on casting speed

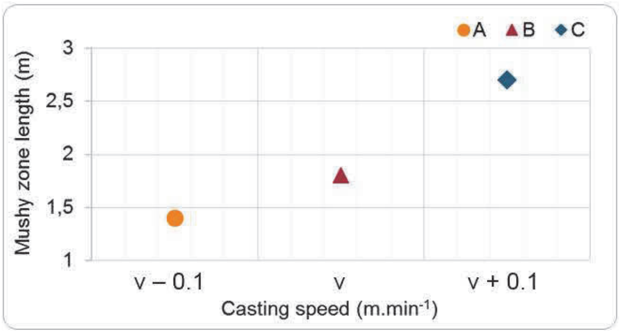


Figure 6 Mushy zone length dependence on casting speed

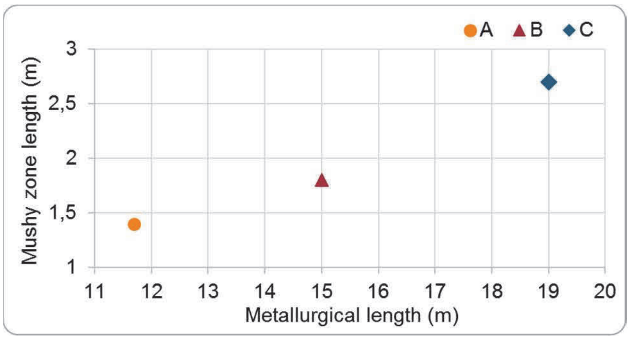


Figure 7 Relation between metallurgical length and mushy zone length

3.2. APM Module results

Through Advanced Porosity Module results, formation of centerline porosity was computed. Based on Liquid pressure and Micro porosity results, inclination to centerline porosity formation under various casting speed of simulated variants was evaluated. Liquid pressure introduces pressure of liquid fraction inside the billet. If the liquid pressure value in axis region reaches 0 bar, we can expect centerline porosity incidence. However, occurrence of zero liquid pressure value in billet does not necessarily mean the centerline porosity formation. If such a case occurs, it is appropriate to confirm centerline porosity incidence on Micro porosity results.

For evaluation of centerline porosity formation, a part of billet was chosen which already didn´t contain liquid core. Evaluated region corresponds to 1.5 m long part of billet in the end of simulated region. In this part, liquid pressure results were evaluated.

Visualization of Liquid pressure results is shown below. **Figure 8a** represents liquid pressure results in longitudinal sections of all three simulated variants. The variants are sorted from the lowest casting speed to the highest. As expected, axial region of billets was proved as critical at all three variants. As can be seen, in each variant axial region, liquid pressure decrease in different ranges was detected. In case of variant A, only minimal pressure drop occurred in small volumes in axial region. For variant A, zero value of liquid pressure wasn’t found. Similar results were found for variant B. Also in case of variant B, zero value of liquid pressure wasn´t found but minimal pressure drop was detected in little larger volumes compared with variant A. Not very satisfactory results were obtained for variant C which was casted by the highest casting speed (v + 0.1 m.min^{-1}). Results of variant C shows liquid pressure drop in relatively large volumes in axial part. In one of these volumes, value of liquid pressure approaching 0 bar was measured. **Figure 8b** represents cross-section of simulated variants and compares the size of the volumes with lower liquid pressure. Cross-section of variant C shows the case in which the value of liquid pressure approaching 0 bar was obtained.

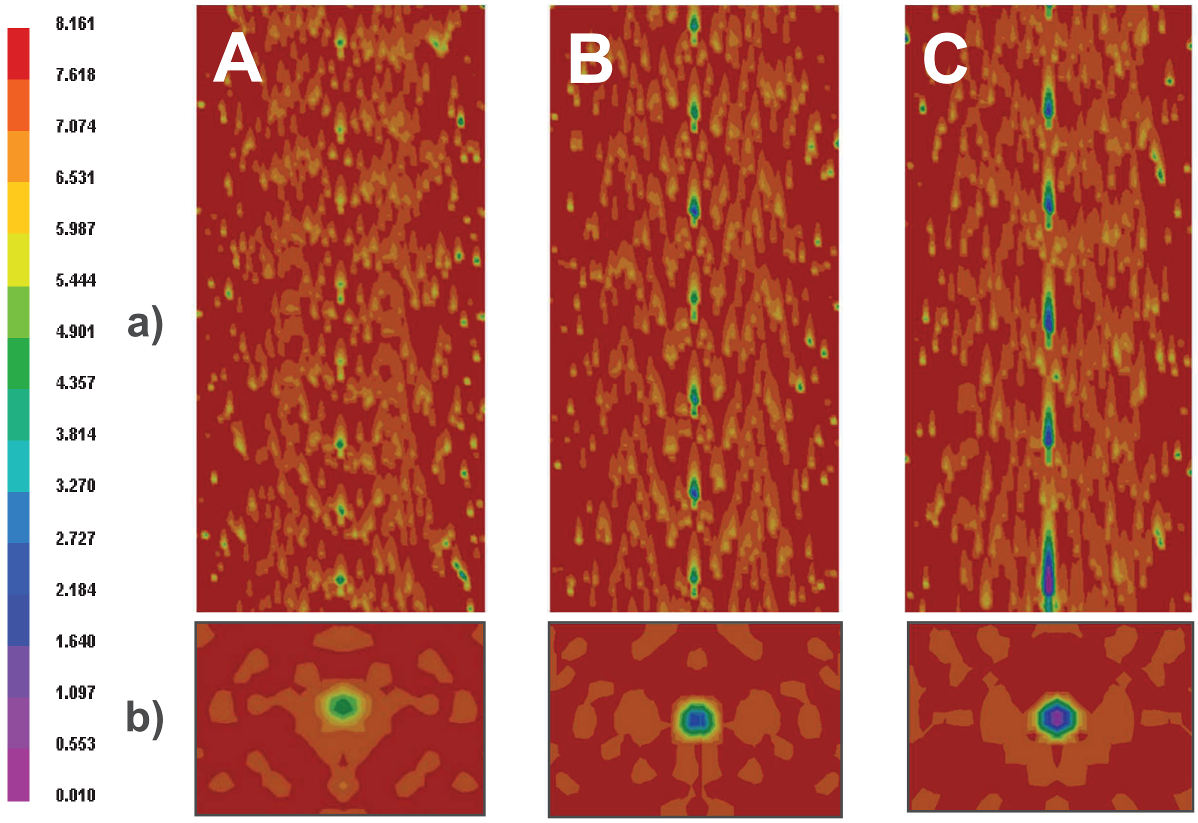


Figure 8 Liquid pressure results a) longitudinal section b) cross-section of billet (detail of axis region)

For easier and more accurate evaluation, export of Liquid pressure data from postprocessor Visual Viewer was carried out. This data was plotted into graph which is shown in **Figure 9**. In **Figure 9** distribution of liquid pressure values in range from -5 to +5 mm around billet axis (0 value on x axis represents the billet centerline axis) can be seen. In accordance with visualization of liquid pressure results (**Figure 8**) we can say that in case of variant A and B the centerline porosity formation didn´t occur. Based on visualized results of variant C, accurate determination of presence of volumes with zero liquid pressure was difficult. However, as shown in **Figure 9**, in the case of variant C, drop of liquid pressure to 0 bar didn´t occur. Likewise, the results of Microporosity didn´t confirm the centerline porosity incidence of variant C. It can be concluded that under current setting of boundary conditions, when casting speed changes in said range (v - 0.1 to v + 0.1 m.min^{-1}) and under constant casting temperature, the centerline porosity formation does not occur.

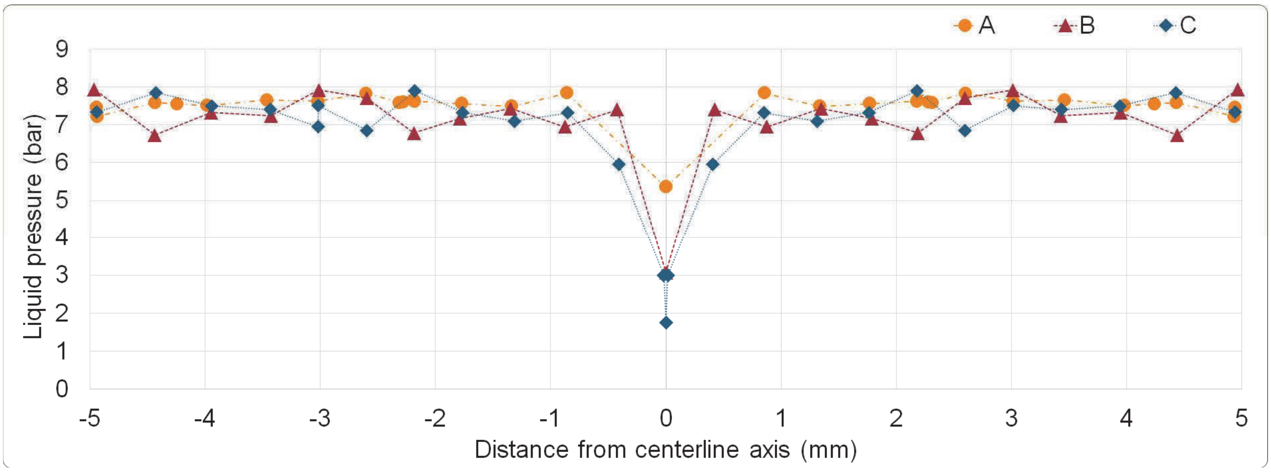


Figure 9 Distribution of liquid pressure in axis area of billets

Figure 10 represents dependence of liquid pressure on casting speed. Liquid pressure increases with decrease of casting speed. **Figure 11** summarizes the relations between metallurgical length, casting speed and liquid pressure. Size of marks is directly proportional to value of liquid pressure. It means that with decrease of mark size, liquid pressure decreases and it results in increase of probability of centerline porosity formation.

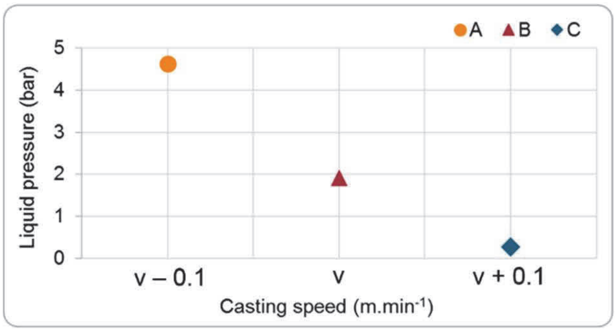


Figure 10 Dependence of liquid pressure on casting speed

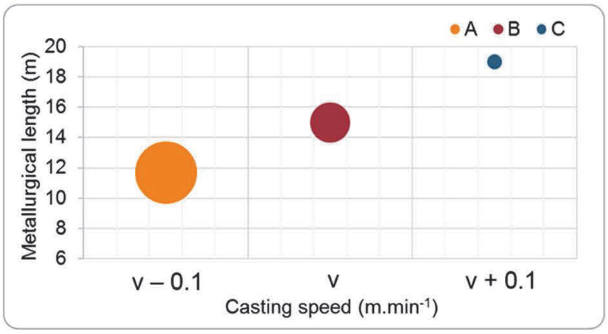


Figure 11 Relation between metallurgical length, casting speed and liquid pressure

4. CONCLUSION

With the aim of centerline porosity prediction, numerical simulations of solidification of continuously cast round steel billets in numerical software ProCAST was carried out. Temperature field, solidification and centerline porosity was simulated. Conclusions of temperature field and solidification results evaluation can be summarized in following points:

- Surface temperature of billet decreases with decreasing casting speed;
- Metallurgical length shortens with decreasing casting speed;
- Mushy zone length shortens with decreasing casting speed.

Centerline porosity was evaluated through Liquid pressure results, which represented pressure of liquid fraction in billet. With decrease of liquid pressure in billet axis probability of centerline porosity formation increased. In each variant, axial region was proved as critical as expected. Conclusions of centerline porosity evaluation can be summarized in following points:

- Size of volumes with lower liquid pressure increased with increase of casting speed;
- Liquid pressure in billet axis decreased with increase of casting speed and extend of metallurgical length;
- Under current setting of boundary conditions, centerline porosity presence wasn’t found out.

Based on presented numerical research, continuous casting of steel with lower casting speed can be recommended. With decreasing casting speed quality of continuously cast round steel billets generally improves. Of course, the casting speed must be select with respect to a casting temperature of steel. If the low casting speed in combination with low casting temperature is set, it may lead to thermal stresses formation and resulted in cracking of billet.

ACKNOWLEDGEMENTS

The work was created with the support of projects of Student Grant Competition No. SP2017/57 and SP2017/58. This paper was created within the project No. LO1203 “Regional Materials Science and Technology Center - “Feasibility Program“ funded by Ministry of Education, Youth and Sports of the Czech Republic.

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