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Possibilities of S-EMS utilization for the improvement of central segregation in continuously cast billets in conditions of TŽ

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ABSTRACT

Purpose: The aim of the paper is to investigate practical possibilities of the strand stirrer (S-EMS) for the improvement of inner quality and central segregation in high carbon billets. An optimal S-EMS setting was proposed for the billet caster producing billets 150x150 mm.

Design/methodology/approach: Impact of different S-EMS settings on central segregation and inner quality of as-cast billets was investigated. A set of longitudinal and transverse samples were analysed including evaluation of baumann prints and central segregation by means of LECO method. Samples of wires for segregation survey in rolled products were picked up as well.

Findings: It was observed that application of the strand stirrer (S-EMS) is capable to suppress central segregation. However, its impact is visible just to a certain stirring level. Subsequent increasing of stirring intensity does not cause further improvement of segregation in the analyzed central part. On the contrary, stronger white band can be seen in the solidification line. Moreover, concentration gradient between the central part and surrounding ring of negative central segregation is lowered. These two effects can play a significant role in the evaluation of segregation level in rolled wires.

Research limitations/implications: Analysis of central segregation in a lower size than used 6 mm.

Practical implications: Optimal S-EMS setting seems to be 300 A/14 Hz.

Originality/value: Impact of S-EMS setting on changes in central segregation of as-cast billets, relationship between central segregation level in wires and cast structure.

Keywords: Continuous casting; Electromagnetic stirring; Segregation

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1. Introduction

The main important quality problem of high carbon steel grades production is the central segregation causing rupture of wires during drawing. Application of electromagnetic stirring during continuous casting of steel represents a possibility how to improve the central segregation.

As generally known, electromagnetic stirring can be implemented in different positions of casters: in the mould (M-EMS), in the secondary zone (S-EMS) and in the zone of final solidification (F-EMS). Nowadays, it is common to use M-EMS for production of high carbon grades. Some of producers try to enhance M-EMS effect by application of either F-EMS or S-EMS.

The billet continuous caster run in TŽ is equipped with M-EMS and S-EMS on all strands. Considering persistent improvement of produced outputs, including central segregation, there was installed a new more powerful S-EMS (with higher flexibility for setting of basic parameters - current and frequency) on one strand of the billet caster. Comparison of basic parameters of both strand stirrers is in Table 1.

The paper presents results observed for different S-EMS settings. Detail analysis of segregation in the central part of billets and its transfer to rolled wires for various stirring intensities are discussed.

Detail layout of central C segregation is very interesting, because there is a positive segregation peak in the billet centre. Then the central C content gradually decreases creating a ring of negative central segregation surrounding the mentioned positive segregation peak. Finally, C content returns back to higher values of approximately heat content [1]. This course of central C segregation was pursued in details and may play a significant role in the evaluation of segregation level in rolled wires assessed according to comparative method described in [2].

Table 1.
Basic parameters of the existing and tested S-EMS

Parameter	Existing S-EMS	Tested S-EMS
Current (A)	28, 42, 56, 70	0-500
Frequency (Hz)	50	0-30
Length (mm)	300	460

Although there are a lot of references about electromagnetic stirring application below the mould in the literature [3,4], it is not possible to find detail information about its effect on segregation course in the metallurgical axe. Practical S-EMS possibilities are not discussed in many cases as well. Most of the papers only give evaluation of big production changes (e.g. non-stirred vs. stirred etc.). Moreover, central segregation transfer from cast to rolled structure is not discussed a lot as well. The paper includes detail analysis of the segregation course in the metallurgical axe of as-cast billets for different S-EMS stirring intensities and its transfer from cast to rolled structure.

2. Experimental procedure

Segregation course in the metallurgical axe of cast billets, their inner quality and segregation transfer from cast to rolled state were investigated for different strand stirrer (S-EMS) settings (Table 2).

Experimental procedure was performed for a constant stirrer frequency and gradual changes of current from 100 to 500 A. Experimental frequency was chosen 14 Hz and should perform the best S-EMS efficiency. The frequency was established with the cooperation of Concast AG, S-EMS manufacturer.

In order to eliminate other parameters (superheat, chemical composition etc.), the whole experiment was performed during one heat of a high carbon grade with the following approximate composition: 0.8% C; 0.7% Mn; 0.3% Si; 0.020% S. Current (stirring intensity) was changed just on one strand, every time in the half of cast billet. Experimental scheme can be seen in Fig. 1. Used stirrer settings are clear from Tab. 2.

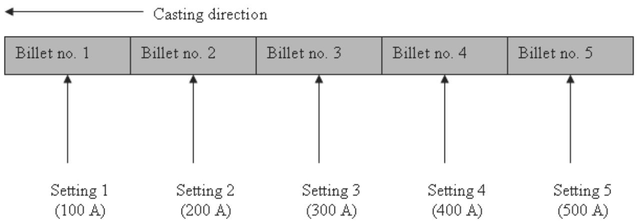

Fig. 1. Scheme of S-EMS adjustment

Table 2.
Experimental S-EMS settings

Setting	Current (A)	Frequency (Hz)
Setting 1	100	14
Setting 2	200	14
Setting 3	300	14
Setting 4	400	14
Setting 5	500	14

Samples for investigation were prepared from approximately 0.5 m long pieces taken from ends of experimental billets. So, one 0.5 m long piece was picked up for each tried setting. Then, these pieces were shorten to the same length of 0.4 m. Two transverse samples (length 350 mm, thickness 35 mm) and one longitudinal sample (thickness 25 mm) were prepared from all the pieces according to Fig. 2.

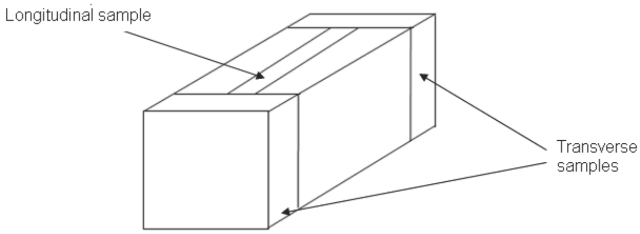

Fig. 2. Sampling scheme of experimental billets

Transverse samples were used for Baumann prints to evaluate inner quality of cast billets (white band and central cracks). Longitudinal samples were cut up into 11 slices. These slices were drilled in centres and obtained chips were analyzed by LECO method to get C content in billets centres. Drilling diameters were 6, 9 and 12 mm. Segregation in cast billets was evaluated by means of *segregation index* which is given by the following equation:

$$S.I. = \frac{C_{LECO}}{C_{heat}} \qquad (1)$$

where C_{LECO} is the central C content (%) measured by LECO method, C_{heat} is the heat C content (%).

Experimental billets were then rolled into wires (diameter 11 mm). A set of samples from wires (serving for assessment of segregation level in rolled material) were taken for each setting. The set of wires included 24 samples in amount. Segregation level in wires were assessed according to [2], which is a comparative method. The method consists in etching of transverse wire samples in nital. The etching reveals a certain spot in the centre of the wire that is considered to be segregation. Based on the size of the spot and its type, so called *penalty points* are assigned for the particular sample. Received penalty points are then re-counted into *segregation coefficient* indicating segregation level in wires. Higher segregation coefficient shows higher segregation level. The average segregation coefficient was set for each setting.

3. Results and discussion

Survey of Baumann prints included observation of central quality (porosity, central cracks) and the white band which forms in the solidification line at higher stirring intensities.

Baumann prints for tested settings are shown in Figs. 3-7. It is clear that central part contains a lot of cracks for lower stirring intensities. With increasing stirring intensity the cracks are gradually disappearing. Central cracks are completely suppressed from 400 A.

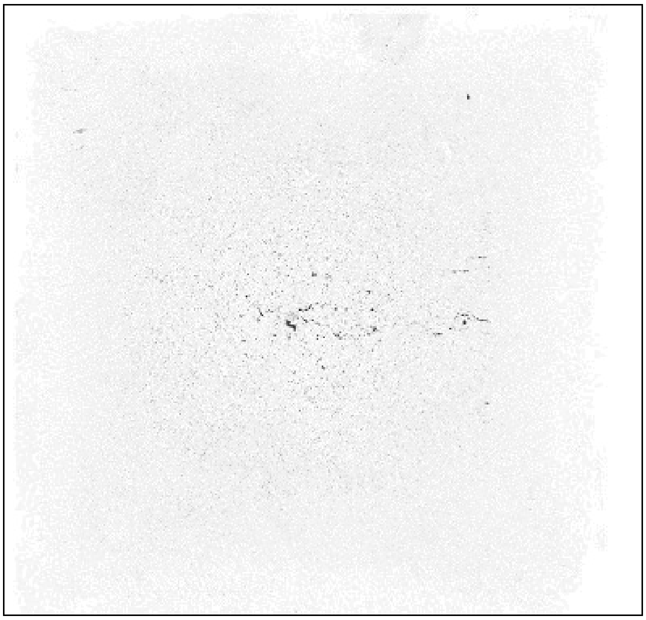

Fig. 3. Baumann print for S-EMS setting no. 1 (100 A/14 Hz)

The white band is not visible up to 200 A. Its first observation can be seen at 300 A but the white band is not clearly obvious. Above 300 A (i.e. 400 A or 500 A), the white band is very strong, which proves very fast motion of the melt in the solidification line for such high intensities.

From the point of view of Baumann prints, the optimal S-EMS stirring intensity seems to be 300 A or more because of good central quality. However, it is also very important to have low central segregation during high carbon grades production. The central segregation of cast billets was evaluated for three areas:

- the central part forming diameter 6 mm (drilling diameter 6 mm),
- ring area 6-9 mm (drilling diameter 9 mm),
- ring area 9-12 mm (drilling diameter 12 mm).

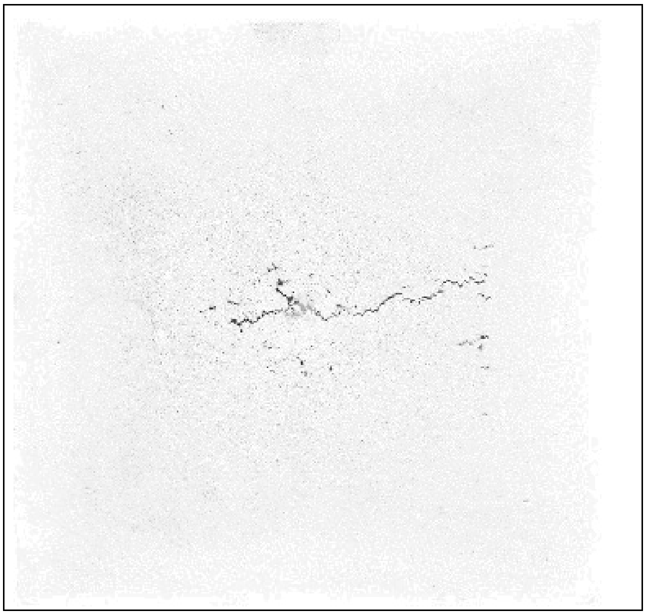

Fig. 4. Baumann print for S-EMS setting no. 2 (200 A/14 Hz)

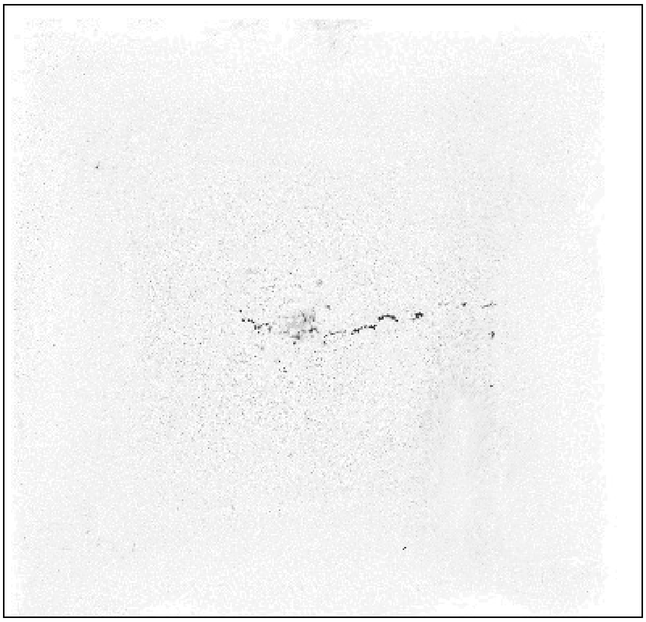

Fig. 5. Baumann print for S-EMS setting no. 3 (300 A/14 Hz)

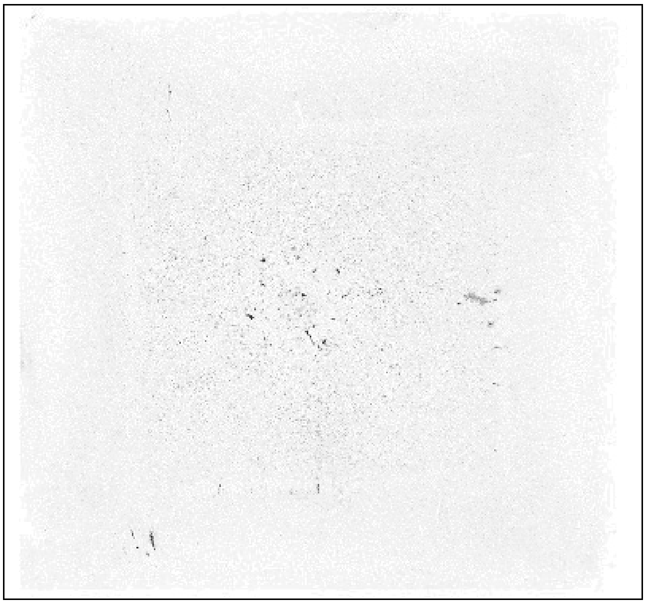

Fig. 6. Baumann print for S-EMS setting no. 4 (400 A/14 Hz)

Fig. 7. Baumann print for S-EMS setting no. 5 (500 A/14 Hz)

Results for checked areas are shown in Figs. 8-10. Central segregation is expressed by segregation index determined according to the equation (1).

The highest central segregation (in the diameter 6 mm - see the Fig. 8) was observed for the lowest tried stirring intensity, i.e. 100 A. Subsequent increasing of stirring intensity to 200 A and 300 A respectively causes decreasing of the segregation index indicating reduction of the central segregation. Further increasing of the strand stirring intensity (to 400 A and 500 A respectively) does not cause another improvement of the segregation in the central part. However, it is a question what segregation course would be observed in a smaller diameter then analyzed 6 mm. But these smaller diameters are very difficult to drill due to too high hardness of the tested material. Finally, we have to note that all the observed segregation indexes are below 1.1, which indicates low segregation level in cast billets for all the experimental settings. These results prove a good performance of M-EMS which is used on all strands of the billet caster in TŽ.

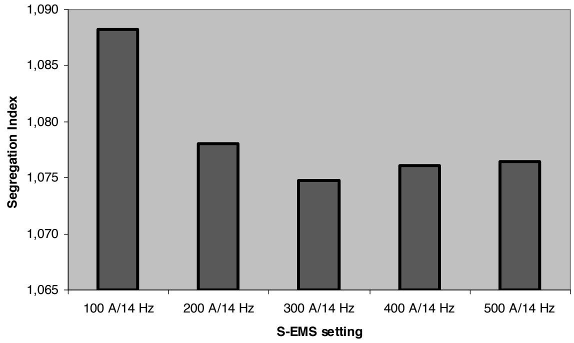

Fig. 8. Segregation index for different S-EMS settings in the central area (drilling diameter 6 mm)

The next area forming ring 6-9 mm (Fig. 9) shows very similar course of the segregation index as the central part. So the segregation index goes down just up to 300 A, then (for 400 A and 500 A respectively) rises a little again.

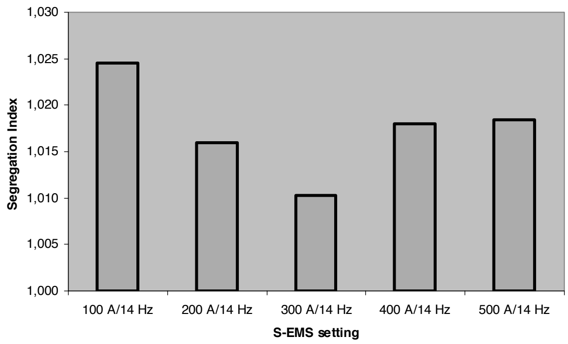

Fig. 9. Segregation index for different S-EMS settings in the ring area 6-9 mm (drilling diameter 9 mm)

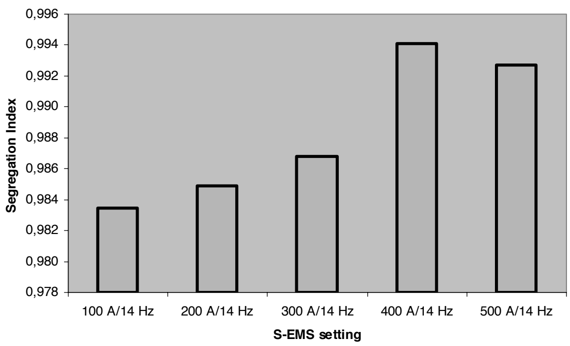

Fig. 10. Segregation index for different S-EMS settings in the ring area 9-12 mm (drilling diameter 12 mm)

Very interesting results were also observed in the last analysed area forming ring 9-12 mm (Fig. 10). According to the earlier experience, this area should represents ring of the negative central segregation surrounding the positive central peak [1]. Obtained results confirm this preposition because segregation index is below 1. So, carbon content in this area is lower than the average C content in the heat. The interesting thing is that the segregation index rises with increasing stirring intensity and close in 1. It seems that the ring of the negative central segregation fades away with increasing stirring intensity.

Above mentioned facts indicate the following segregation behaviour. First, central segregation (in the diameter 6 mm) is reduced with increased strand stirring intensity. Subsequent increasing of the S-EMS intensity is not capable to reduce segregation in the central part anymore but influences C content layout in billets centre so that there is a lower C concentration gradient between central positive segregation peak and the surrounding ring of the negative central segregation.

The situation is clear from Fig. 11, where course of the central segregation index is drawn just for 3 intensities: 100 A, 300 A and 500 A. It is visible drop of the segregation index when S-EMS stirring intensity is changed from 100 A to 300 A. Subsequent increasing of S-EMS stirring intensity from 300 A to 500 A does not reduce central segregation index but moves arms of the segregation index in rings 6-9 mm and 9-12 mm up. This movement of the arms upwards indicates decreasing of C concentration gradient between central positive peak and surrounding ring of the central negative segregation.

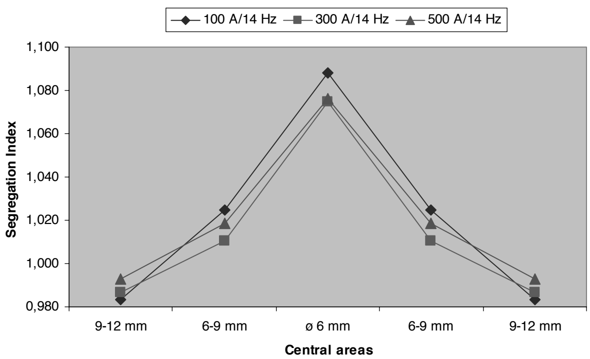

Fig. 11. Course of the segregation index for different S-EMS settings in billets centre

It seems that stirring in the secondary cooling zone influences C content layout in billets centre, which may be related with changes in creating of miniingots. So, more detail analysis regarding miniingots forming is needed.

Described changes in the central C content layout can have a serious impact on the assessment of the segregation level in wires. As mentioned earlier, segregation level in wires can be assessed by the comparative method according to [2]. Because the transfer of the central segregation from cast to rolled state is not clear it is not possible to predict how the described findings will influence this segregation assessment.

Assessment of the segregation level in wire for each tried setting is depicted in Fig. 12. It can be observed that the segregation level in wires is improved up to 300 A, which is characterized by decreasing segregation coefficient. The reason is that the segregation index in the central part of billets goes down in this range of stirring intensities.

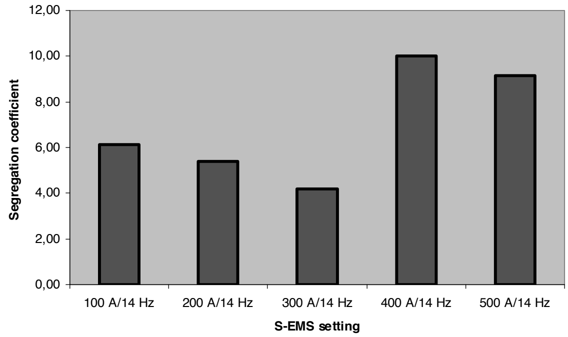

Fig. 12. Assessment of the segregation level in wires by means of the segregation coefficient

Subsequent stirring intensity increasing to 400 A and 500 A respectively causes significant increasing of the segregation coefficient indicating deterioration of the segregation level in wires. The main reasons for such deterioration of the segregation level can be as follows:

- presence of the strong white band for intensities above 300 A,
- difference in the C segregation layout in billets centre.

Generally, presence of the strong white band is not considered to be harmful for high carbon grades. However, because the exact relationship between inner billets quality (including central segregation, white band etc.) and segregation level in wires assessed by means of segregation coefficient is not clear, presence of a strong white band in billets cannot be neglected and may have an influence over evaluation of the segregation coefficient.

Carbon content layout in billets centre can influence the segregation coefficient in wires as well. If there is a higher concentration gradient in the billet centre (i.e. higher difference between central positive segregation peak and surrounding ring of the negative central segregation - see Fig. 11), so the central segregation dissolution will be faster during billets re-heating in the furnace at the rolling mill. The reason is that carbon diffuse from areas with higher concentration towards areas with lower concentration during billets re-heating. So, the higher concentration gradient in billets centre represents a higher potential for acceleration of diffuse processes and the dissolution of the central segregation will be faster. As it is evident from Fig. 11, concentration gradient is higher with stirring intensity 300 A in comparison to 500 A (or 400 A respectively). Therefore, faster segregation dissolution can be expected for the intensity 300 A, which reduces segregation level in the wire.

Based on the described information, it is possible to reduce central segregation by the strand stirrer (S-EMS) application. However, just up to the certain intensity. Subsequent increasing in the stirring intensity does not reduce segregation in the central part of billets. Very high stirring S-EMS intensities cause both creating the strong white band and decreasing the concentration gradient between central positive segregation peak and surrounding ring of the negative central segregation. It seems that the optimal setting of the discussed S-EMS is 300 A (14 Hz) which gives its best performance evaluated by segregation coefficient.

4. Conclusions

Investigation of S-EMS performance on segregation course and inner quality of billets was carried out. Assessment of the segregation level in wires according to comparative method [2] was done as well. The trial involved changes of the stirring intensity by means of current adjustment between 100 and 500 A. Frequency was kept on 14 Hz during the whole test. The main findings are as follows:

- The stirrer is not capable to create the white band up to 200 A. Its first observation can be seen at 300 A but the white band is not clearly obvious. Above 300 A (i.e. 400 A or 500 A), the white band is very strong, which proves very fast motion of the melt in the solidification line for such high intensities.
- Segregation in the analyzed central part (diameter 6 mm) is decreasing up to 300 A. Further increasing of the S-EMS stirring intensity (to 400 A and 500 A respectively) does not cause another improvement of the segregation in the central part. However, it is a question what segregation course would be observed in a smaller diameter then analyzed 6 mm.
- Segregation coefficient expressing segregation level in wires goes down up to 300 A. The reason is that the segregation index in the central part of cast billets goes down in this range of stirring intensities.
- Subsequent S-EMS stirring intensity increasing to 400 A and 500 A respectively causes increasing of the segregation coefficient indicating deterioration of the segregation level in wires. The main probable reason is difference in C concentration layout in billets centre. Presence of the strong white cannot be excluded as well.

Based on the described information, it is possible to reduce central segregation by the strand stirrer (S-EMS) application. However, just up to the certain intensity. Subsequent increasing in the stirring intensity does not reduce segregation in the central part of billets. Very high stirring S-EMS intensities cause both creating the strong white band and decreasing the concentration gradient between central positive segregation peak and surrounding ring of the negative central segregation. It seems that the optimal setting of the discussed S-EMS is 300 A (14 Hz) which gives its best performance evaluated by segregation coefficient.

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