A MAJOR STEP FORWARD IN IMPROVING INTERNAL SLAB QUALITY – DEVELOPMENT AND FIRST IMPLEMENTATION OF THE SINGLE ROLL DYNAGAP (SRD) SEGMENT AT TERNIUM BRASIL*

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Abstract

For many years, Dynamic Soft Reduction has been regarded as a proper method in improving internal quality of slabs. Even though processes models improved significantly over the past years, the efficiency of Soft Reduction was always limited by the discretization error, which inherently exists if segment rollers cannot be positioned individually. The recently developed SRD segment type allows for an individual roller positioning within the mushy zone by avoiding any discretization deviation from the optimal gap. This paper provides a detailed technological overview of the SRD segments as well as operational results at their very first implementation at Ternium Brazil.

Keywords: Soft Reduction, Internal slab quality, SRD Segments.

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1 INTRODUCTION

Requirements on slab centerline segregation are becoming increasingly more demanding, especially with applications, which require high strength, toughness and good weldability. Slabs with low segregation intensity are as well microstructurally more homogeneous in subsequent rolling and other thermomechanical processes.
Studies [1,2] have shown that segregation is caused by the mass flow of solute-enriched liquid between the dendrites during solidification, which leads to a concentration of elements in the molten steel at the point of final solidification. Centerline segregation reveals itself as inhomogeneities in the center area of the strand, where the final solidification takes place. Together with centerline segregation, porosities may form due to an inadequate liquid pool available to feed the solidifying matrix, leaving voids at the centerline of the strand.

The main factors of the continuous casting process that have an influence on the intensity of the centerline segregation are:

- Chemical composition of the steel especially elements which are prone to segregation such as C, Mn, S and P
- Superheat [3]
- Casting speed [4] and its variation
- Casting width and thickness
- Spray pattern of secondary cooling nozzles [5]
- Geometry of the machine [2] (roll gap profile and deviations of alignment)

Adequate countermeasures to reduce the severity of segregation are:

- Adjustment and monitoring of the geometry of the machine [6]
- Precise prediction and position control of the solidification end point [2]
- Electromagnetic stirring [3]
- Soft reduction [5, 6, 7, 8, 9]

Soft reduction is a state of the art technology for reducing centerline segregation and is generally understood as a reduction of the strand cross section (thickness) during the continuous casting process close to the point of final strand solidification. Even though process models [10, 11, 12] have improved significantly over the past years, in order to calculate the point of final solidification with even higher precision, the efficiency of soft reduction was always limited by an inherent discretization when using conventional segments, where a number of rollers are mounted on the same segment frame and cannot be positioned individually (see Figure 1a). The latest developed SRD (Single Roll DynaGap) Segment type by Primetals Technologies allows for an individual roller positioning within the mushy zone by avoiding any discretization from the aim gap (see Figure 1b).
Due to this earlier mentioned discretization, it´s widely accepted as a good practice to position the point of final solidification at the position of the last roller of a conventional segment by adjusting the casting speed accordingly (see Figure 2a). In this favorable casting condition, the soft reduction profile is applied as a linear reduction profile. Contrarily, the SRD Segment technology provides full flexibility in defining the Soft reduction profile independent of the position of the point of final solidification inside the segment. Figure 2b shows exemplarily a progressive reduction profile, where the reduction rate is increased steadily until the point of final solidification.

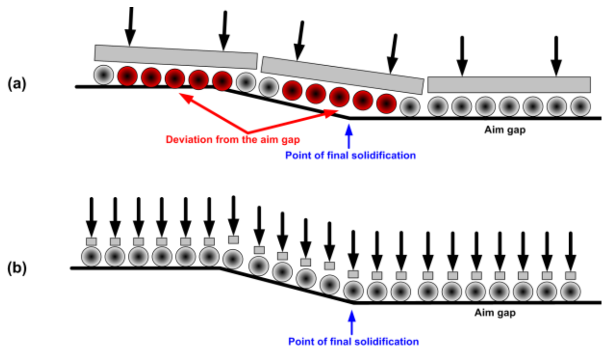

Figure 1. (a) Soft reduction with standard segments; (b) Soft reduction with SRD Segments with individual roller positioning.

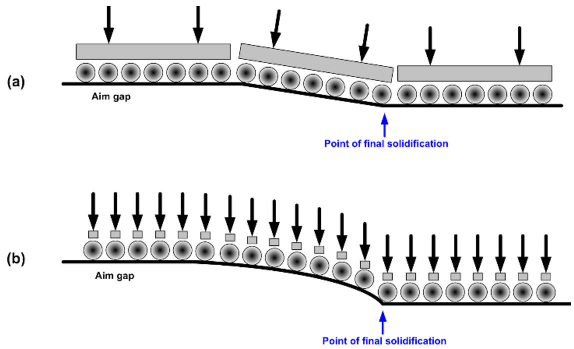

Figure 2. (a) Soft reduction with standard segments – linear soft reduction profile; (b) SRD Segments providing full flexibility in defining the soft reduction profile.

At the Ternium steel plant in Rio de Janeiro, Brazil, the two 2-strand casters with installed casting thicknesses of 255, 220 and 200mm are equipped with soft reduction technology since their startup in 2010. Soft reduction is applied for all casting thicknesses and steel grades in production, whereas the amount of the applied soft reduction process varies between 1.5 – 2.5% of the casting thickness depending on the steel grade group. In normal casting operation, soft reduction is applied in one to three segments before the point of final solidification (as a portion of the length of the mushy zone which itself depends on steel grade, thickness, secondary cooling conditions, etc.). The soft reduction taper ranges therefore between 0.8 – 1.1mm/m.

1.1 Modenization project

In August 2015 Ternium (former thyssenkrupp CSA Siderúrgica do Atlântico) awarded Primetals Technologies for the modernization of the two 2-strand slab casters. The two main goals of the modernization were the increase of production capacity by extension of the metallurgical length and the improvement of internal slab quality by focusing on the soft reduction process. The improvement of the calculation precision of the point of final solidification was accomplished by upgrading the Level 2 System with the newest available process models for secondary cooling (DynaPhase and Dynacs 3D) and segment control (DynaGap 3D). The earlier mentioned inherent discretization due to the positioning of standard Smart Segments was encountered by installing two SRD Segments on strand 1 of CCM1.

1.1.1 Dynacs 3D

At the startup in 2010 both 2-strand casters were equipped with the first-generation Dynacs system, introduced in the 1990s, which was characterized by a two-dimensional temperature calculation of the strand center. The strand corners were largely neglected by the process model. Continuous improvements in computer performance have made it possible to calculate the temperature at any point within the entire strand in real time, in a full three-dimensional mode and in a sufficiently fine discretization yielding very detailed temperature profiles as can be seen for strand surface and strand center in Figure 3 and Figure 4.

Figure 3. Visualization of the surface temperature.

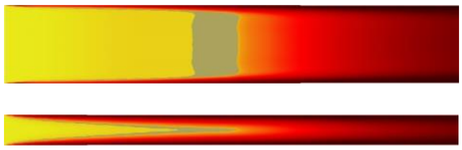

Figure 4. Visualization of the center temperature (enhanced colors for solidification area).

The model is based on an explicit finite-volume approximation that solves the heat transfer equation and takes into consideration temperature-dependent density as well as the position-specific slab thickness and width. Dynacs 3D accurately assesses the heat transfer from the slab surface resulting from radiation, heat transfer to the rolls, natural convection and spray water. Furthermore, Dynacs 3D can be applied for both spray cooling and air-mist cooling, and takes into account the spray-distribution pattern of the nozzles. The result is an even more precise determination of the strand surface temperature and the final point of strand solidification. This detailed assessment of the heat transfer additionally allows for the calculation of the non-uniform solidification front due to non-homogeneous heat removal until the final solidification. Based on the precise temperature calculations the Dynacs 3D model allows to specify the desired surface temperature. The control algorithms of Dynacs 3D calculate the water-flow setpoints to achieve the target strand-surface temperature values. The online HMI is shown in Figure 5.

Figure 5. Dynacs 3D implemented in Level 2 HMI.

The offline maintenance and setup system allows the cooling-relevant settings to be configured in such a way that the spray-water distribution in the cooling zones and the application of cooling practices are optimized based on quality results or operational needs. A built-in offline simulation system enables comprehensive testing of new parameter settings prior to application in the production process.

1.1.2 DynaPhase

DynaPhase is a software package which calculates the temperature depending material data needed by Dynacs 3D. For this, a substitutional solution model for the Gibbs free energy is employed. To determine the free parameters of the model the CALPHAD approach is used. This model is suitable to predict the equilibrium liquidus and solidus temperature as well as the thermos-physical material data depending on the chemical analysis of the actual steel grade. However not just the thermodynamic equilibrium is of interest. To determine the solidification interval, micro segregation has to be considered as well. Therefore, a combination of the substitutional solution model with a model describing the interdendritic solidification depending on the secondary arm spacing of the dendrites and the cooling rate of the steel is included. This model guarantees mass balance at the phase interface, which means that the model accounts for diffusion across the phase interface. The equations of these two models have to be solved simultaneously to provide liquidus and liquidus temperature as well as thermos-physical material properties. Moreover, to improve the accuracy of the predicted liquidus and solidus temperature the model has been extended by incorporating a model describing the formation of compounds, i.e. non-metallic precipitations, from the liquid phases. The benefits of accurate steel composition-related thermal properties (see Figure 6) as an input to Dynacs 3D cannot be overstated in terms of calculation precision.

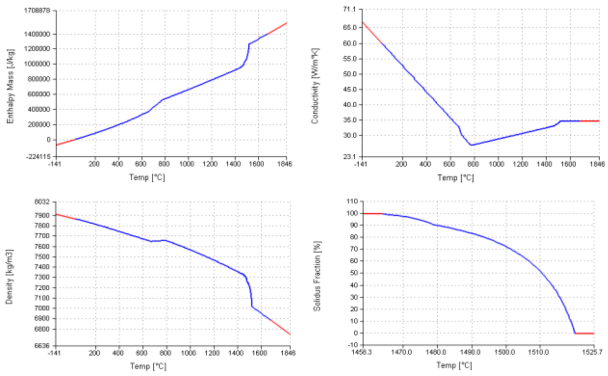

Figure 6. Calculated temperature depending material properties based on the chemical composition.

The original Dynacs system, which was implemented since the startup of both casters, used simple, group-related data in which a steel grade group would have a range of carbon content. However, the actual steel being cast may have a different carbon, manganese or some other alloying element content. For example, the resulting fraction solid for the differences in composition can have a significant effect on the final solidification. Figure 7 demonstrates the effect on the solid fraction range due to a difference in carbon content of 0.05%. In this example, the shift of the final solidification point due to the use of the real chemical composition equals 0.7m.

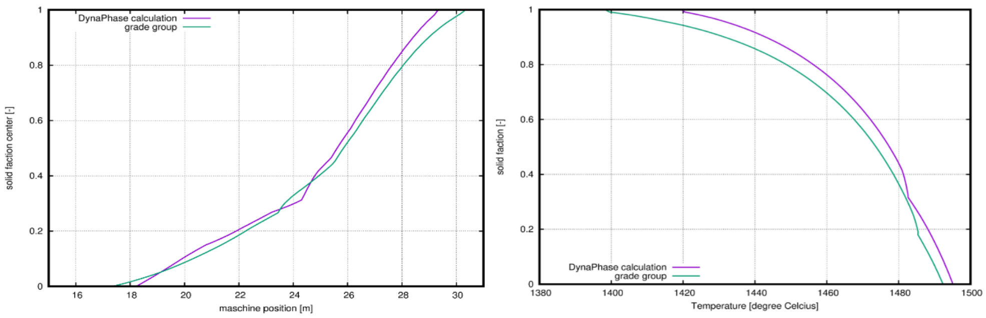

Figure 7. Composition-critical solidification.

1.1.3 DynaGap3D

Based on the online information provided by the Dynacs 3D thermal tracking model, DynaGap 3D dynamically calculates the setpoints of the adjustable roll gap. The new DynaGap 3D model also takes into consideration the steel shrinkage as calculated by Dynacs 3D, which allows a more precise adjustment of the roll-gap settings to be achieved. This minimizes steel flow into the liquid or mushy strand center and results in a significant reduction of macro segregations along the entire length of the solidifying strand. Supervision of the roll engagement, depending on the state of solidification (liquid, mushy or solid) and the calculated strand thickness profile, is a decisive factor for precise roll adjustments and thus improved product quality. An optimized roll engagement also reduces excessive forces on the strand and decreases roller wear. This further increase casting flexibility and product quality. DynaGap 3D makes it possible to freely define start-up and tailing strategies based on the strand thickness, steel grade, casting status or other events. In this way roll damage and production interruptions, which may arise from the different casting behavior of the cold strand head or end, can be avoided. The online HMI is shown in Figure 8.

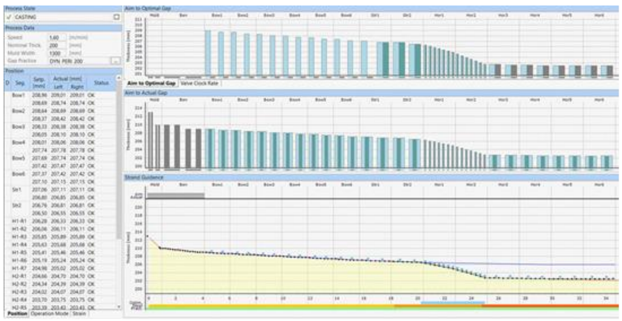

Figure 8. Gap control of DynaGap 3D implemented in Level 2 HMI.

The offline maintenance and setup system allows the adjustment of gap practice-relevant settings to be configured. A built-in offline simulation system enables testing of new parameter settings prior to application in the production process in order to avoid machine damage or production loss.

1.2 SRD Segment technology

As already mentioned in the previous chapter, SRD Segments are able to adjust each roller on the upper frame individually in order to follow precisely the solidification point during soft reduction without any discretization. Primetals

Technologies developed this special type of segment in order to offer an upgrade solution for casters that produce sensitive steel grades, which inherently requires the interchangeability with Smart Segments as well as with other segment designs. Figure 9 shows an assembly of an SRD Segment as installed in CCM1. The main components of this segment type are one outer bow, two lateral guidance frames and seven Single Roller Units.

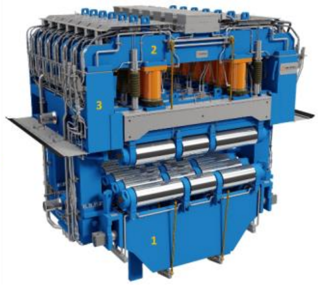

Figure 9. Assembly of the SRD Segment.

The Outer bow, as shown in Figure 10, comprises of four connection surfaces for the lateral guiding frame, one driven and six idler rollers, water connections and segment fixations. The water connections and segment fixations are identical to those of the conventional Smart Segments, which means that this type of segment is 100% interchangeable at any horizontal position.

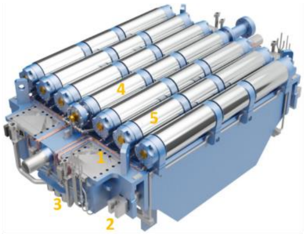

Figure 10. Outer bow of the SRD Segment.

The lateral guidance frame provides the mounting positions for the fixed part of the individual Single Roller Units (SRU), where adapter for roller and bearing cooling and spray nozzles are integrated.

Each segment consists of seven identical Single Roller Units, which consist of a support beam, two lifting cylinders and a roller beam. Additionally on each SRU are mounted a hydraulic block, two position sensors and spray nozzles of the secondary cooling system. The maximum force acting on a single roller can never exceed the maximum available hydraulic force, since each roller is positioned individually. Each roller is therefore overload-protected, which prevents damage to the bearings and the roller surface.

Since each adjustable roller is embedded in a functional unit that can be quickly exchanged (see Figure 12). This exchange can be performed in the maintenance area or in the caster during a casting break. Before insertion into the segment, each individual roller unit can be pretested and calibrated.

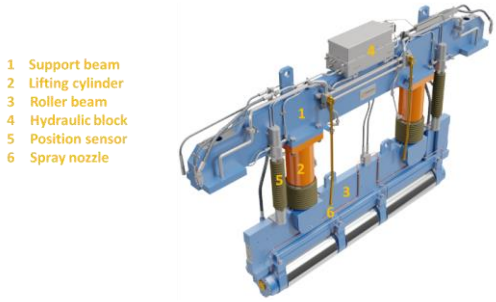

Figure 11. Single Roller Unit (SRU) of the SRD Segment.

Since each adjustable roller is embedded in a functional unit that can be quickly exchanged (see Figure 12). This exchange can be performed in the maintenance area or in the caster during a casting break. Before insertion into the segment, each individual roller unit can be pretested and calibrated. When this roller unit is being installed, all utility supplies are connected automatically and only two bolts need to be tightened. This enables a simple handling of individual rollers instead of the need to exchange a whole segment when only one roller needs maintenance.

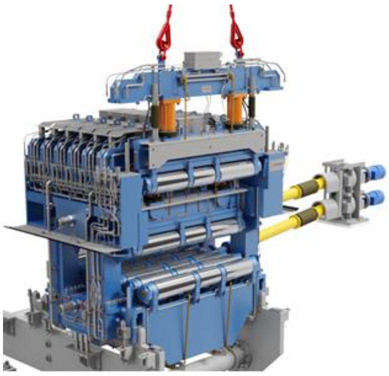

Figure 12. Exchange of Single Roller Unit (SRU).

The individual roller units using the already proven, and in conventional segments implemented, DynaGap positioning technology using simple on/off valves. Instead of 4 individual axes of a convectional Smart Segment, 14 individual axes need to be controlled simultaneously. The new developed SRD Segment controller, which was installed on all six segment positions of the horizontal part of strand 1 of CCM 1 is able to handle both segment types. The SRD Segment controller distinguish automatically between both segment types and sends this information to the Dynagap 3D system in order to configure the caster setup.
In September 2016, the strand extensions with conventional Smart Segments and upgraded Level 2 automation package were installed and in June 2017, the installation of two SRD Segments was accomplished. After a short cold commissioning phase, the SRD Segments entered in operation on 15th of July 2017.

2 DEVELOPMENT

All test results presented in the present work were accomplished at a casting thickness of 220mm. In order to provide a feasible casting speed for different steel grades, the two SRD Segments were installed at segment position 9 and 10 which represents the position of the first and second horizontal segment (see Figures 13 and 14).

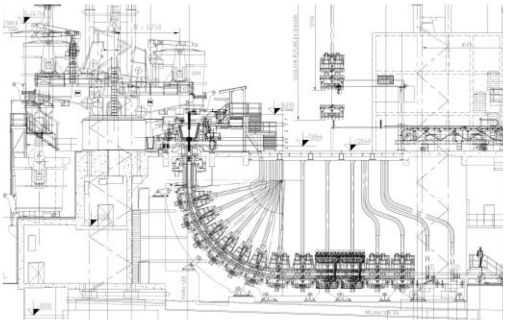

Figure 13. Installation of two SRD Segments on strand 1 of CCM1 at position 9 and 10.

Figure 14. Installation of two SRD Segments on strand 1 of CCM1 at position 9 and 10.

According to the test plan shown in Table 1, the trials were done when casting peritectic and medium carbon steel grades. The soft reduction amount of the strand with SRD Segments was increased with every trial accomplished and reached as a maximum 200% of the standard value in Trial 5.

Table 1. Test plan

Trial	Steel grade group	%C	%Mn	%P	%S	Casting speed (m/min)	Super heat	SR amount SRD (% standard)	SR amount conv. segment
1	Peritectic	0.146	0.565	0.013	0.005	1.30	20°C	100%	Standard
2	Peritectic Alloyed	0.104	0.400	0.014	0.006	1.30	16°C	125%	Standard
3	Peritectic	0.167	0.698	0.014	0.006	1.30	28°C	125%, 150%	Standard
4	Medium carbon	0.202	0.476	0.020	0.006	1.25	19°C	133%	Standard
5	Peritectic	0.089	0.921	0.014	0.003	1.25	14°C	175%, 200%	Standard

In trials 2 – 5, a progressive soft reduction profile was applied on strand 1, where SRD Segments were installed. Thereby, the soft reduction was carried out in two segments, where 12 of the total 14 rollers (2 segment with 7 rollers each) were applying the main portion of the total reduction in the mushy zone and a much smaller portion of the total reduction was applied in the already fully solidified strand. Figure 15 shows typical screen shots of the gap profile shown in the Level 2 online HMI during the trials.

(a)
(b)
(c)

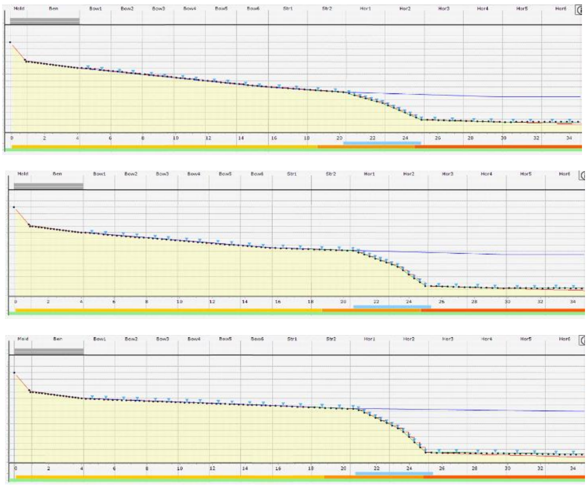

Figure 15. Gap profiles shown in the Level 2 HMI during the trials: (a) Standard soft reduction practice using Smart Segments, SRD practices with increased reduction 150% (b) and 200% (c) using SRD Segments.

At Ternium, the internal integrity of slabs with respect to centerline segregation is regularly monitored by applying a macro-etch technique and rating on a Mannesmann scale of 1 to 5. Figures 16 – 20 show macro-etch results of longitudinal samples of the accomplished trials according to Table 1. All samples were taken from the center of the slab (half width).

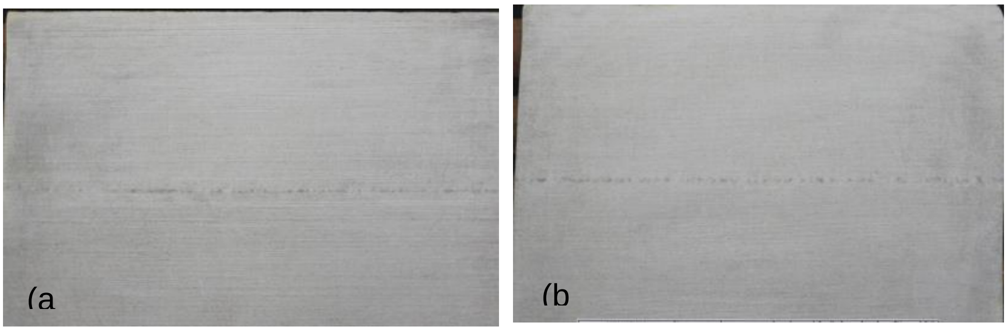

Figure 16. Macro etches of Trial 1. Application of standard soft reduction practice using conventional Smart Segments (a) and SRD Segments (b).

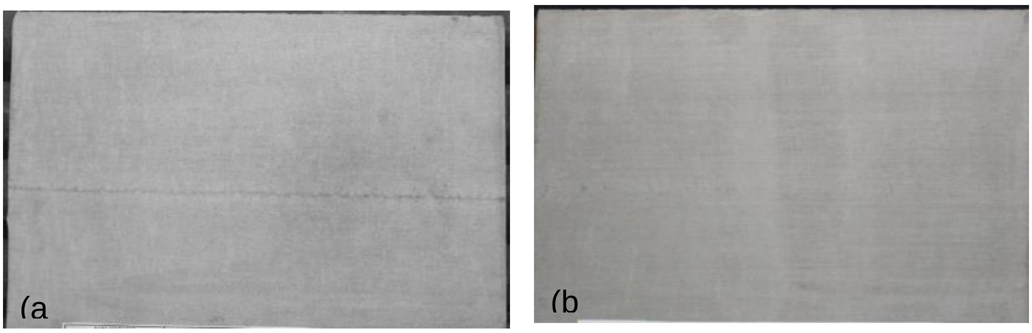

Figure 17. Macro etches of Trial 2. Application of standard soft reduction practice using conventional Smart Segments (a) and SRD Segments (b).

Figure 18. Macro etches of Trial 3. Application of standard soft reduction practice using conventional Smart Segments (a), increased soft reduction (125%) using SRD Segments (b) and increased soft reduction (150%) using SRD Segments (c).

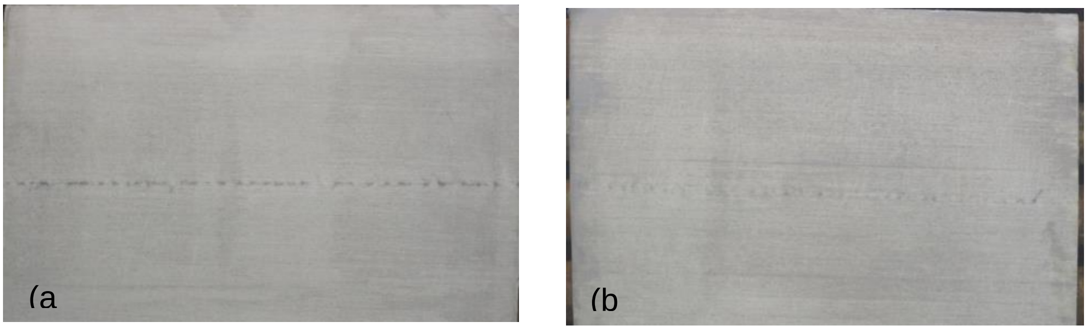

Figure 19. Macro etches of Trial 4. Application of standard soft reduction practice using conventional Smart Segments (a) and increased soft reduction (133%) using SRD Segments (b).

Figure 20. Macro etches of Trial 5. Application of standard soft reduction practice using conventional Smart Segments (a), increased soft reduction (175%) using SRD Segments (b) and increased soft reduction (200%) using SRD Segments (c).

In trial 1, a standard soft reduction practice, which is used for production of peritectic steel grades, was applied on both strands. No significant difference in the level of centerline segregation can be seen, since in both cases the point of final solidification was positioned at the end of segment 10, which means that equal conditions were present on both strands (see Figure 16). Therefore, results taken from samples of strand 2, where a standard soft reduction practice was applied were taken as a reference.

Figure 17 shows a significant improvement in the level of centerline segregation in the results of trial 2. It should be pointed out, that the point of final solidification was positioned in both cases in the middle of segment 10 (4th of 7 rollers). The elevated centerline segregation was caused therefore by the fact that at least three rollers of segment 10 were doing soft reduction in the already solid part of the strand. This trial shows clearly the big advantage of the SRD technology in that the centerline segregation does not depend on the position of the point of final solidification end since all rollers are individually positionable.

Figures 18 – 20 show again a significant improvement in centerline segregation using the SRD technology. The macro-etch results show the best results when a soft reduction of 200% of the standard value was applied.

3 CONCLUSION

The modernization of Ternium´s two-strand slab casters in Rio de Janeiro, Brazil with the latest generation of process models and SRD Segment technology with individual roller positioning resulted in a big step forward in improving the centerline segregation. All taken samples with SRD Segments showed a significantly better internal quality compared to conventional SMART Segments. With this significant improvement in internal quality, its possible to enter in new markets with more demanding requirements due to more critical applications. Until end of March 2019 in total 1.9 Mt have been produced using SRD segments. Strand 2 will be upgraded to SRD technology in May 2019 in order to apply practices with increased soft reduction on both strands of CCM1. The upgrade includes as well the purchase of four additional SRD Segments.

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