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Metallurgy

Application of soft reduction technique to continuous-casting billets

Mingzhong Liu[1)], *Jingshe Li*[1)], *Shiqi Li*[1)], *Hongjun Yan*[1)], *Yingjun Fan*[2)], *and Mingsheng Yang*[2)]

1) Metallurgical and Ecological Engineering School, University of Science and Technology Beijing, Beijing 100083, China
2) Xinxing Ductile Cast Pipe Group Co. Ltd., Handan 056308, China
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Abstract: Soft reduction technique can decrease the presence of central porosity and centerline segregation, and thus to enhance the internal quality effectively. In order to produce high quality billets, Xinxing Ductile Cast Pipe Group Co. Ltd. of China has installed a set of soft reduction apparatus on No.1 caster and has achieved a great success. The principle, operating conditions and controlling factors, and the specification of soft reduction for solidifying billets are introduced. In order to make the effectiveness of soft reduction clear, metallurgical evaluation is made. The results indicate that soft reduction can increase equiaxial zone by 3%.

Key words: continuous casting; central porosity; segregation; soft reduction

1 Introduction

With the rapid development of technologies, the great demand has been put on the steel with high quality. Soft reduction technique is applied to enforce a certain amount of press on the zone immediately prior to the final point of solidification so as to eliminate the porosity, which is formed at the final phrase. Meanwhile, this kind of reduction functions as a preventive force for the forming of "Micro-crystal Block" which can cause macro-segregation along the centerline [1-3]. By using soft reduction technique, the following advantages can be obtained: (1) It can reduce the carbon segregation in high-carbon steel and improve center soundness at the same time, especially for bearing steel, wire used in reinforced concrete as well as steel wire used in meridian line tyre; (2) It can improve the center porosity in medium carbon steel with low compression ratio [4, 5].

2 Operating conditions and technological controlling factors of soft reduction

Figure 1 shows the working conditions, internal solidification structure in the reduction area using soft reduction technique. It shows that the amount of reduction has eliminated the segregation liquid at the center and has enhanced the porosity meanwhile [6].

One strand of No.1 twin-strand continuous casting machine in Xinxing Ductile Cast Pipe Group Co. Ltd. of China has been installed with the soft reduction apparatus and great success has been achieved. The main specifications of the caster are shown in **table 1**, and the specification of soft reduction is given in **table 2**.

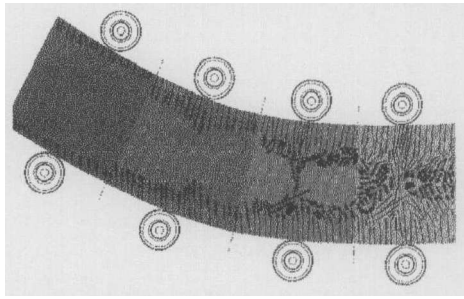

Figure 1 Mechanism of soft reduction technique.

Table 1 Main specifications of the caster

Item	Specification
Mold size / mm	120 × 120
Bending radius / m	5.25
Distance between the rolling area and the mold / mm	8650
Casting speed / (m·min^{-1})	2.3-2.8
Mold length / mm	812
Type of secondary cooling	Totally with water
Steel grade	20MnSi, Q235

Compared with the billets without soft reduction, the internal quality has been improved greatly. It is demonstrated as follows: (1) Soft reduction can improve the solidification structure. In other words, reasonable soft reduction amount can reduce the coarse dendrite crystal and equiaxed crystal. It can also amplify the equiaxed zone and enhance the ratio of it to the total area. (2) With the treatment of soft reduction equipment, the segregation of chemical composition

Corresponding author: Jingshe Li, **E-mail:** lijingshe@metall.ustb.edu.cn

(C, P, S) as well as the surface and internal qualities have been improved. In particular, the number of strong crystal grains has been lowered greatly.

Table 2 Specification of soft reduction

Heat No.	Reduction amount / mm	Working rolls / Sets	Working pressure of stands / MPa	Working pressure of training roll / MPa	Tundish temperature / °C			Casting speed / (m·min^{-1})	
					Early	Mid	Final	1st	2nd
C15388	4	3	7	7	1537	1533	1529	2.54	2.59
B15495	4	4	7	7	1524	1525	1522	2.60	2.62
B15164	5	3	8	8	1536	1532	1522	2.65	2.66
A15390	5	4	7	7	1600	1537	1534	2.67	2.68
C15287	6	3	8	8	1530	1538	1530	2.68	2.60
B15593	6	4	7	7	1537	1532	1530	2.71	2.70
A15079	7	3	8	8	1517	1519	1517	2.86	2.90
A15282	7	4	8	8	1530	1522	1525	2.78	2.78

Figure 2 is the forming process sketch of macro-segregation. To prevent the natural forming of macro-segregation has been the initial aim of soft reduction. As can be seen from **figure 3**, by casting pressure upon the surface at the area near the solidification ending position, the segregation liquid rich with the residual and alloying elements can be forced back to the bath. Those elements thus can be evenly distributed at the center and so as to achieve the goal of lowering macro-segregation.

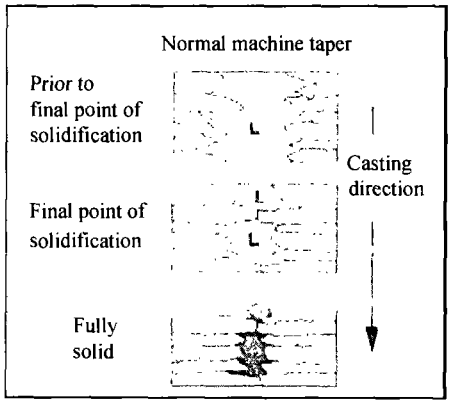

Figure 2 Macro-segregation during steel solidification.

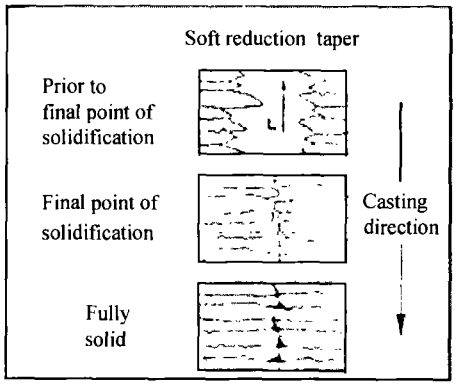

Figure 3 Effect of soft reduction on macro-segregation.

From the experience of using soft reduction across the world, three key points have to be taken into consideration in billet casting with soft reduction [7]:

(1) The ending position of solidification must reside within the soft reduction zone, with the ideal location immediately prior to the exit of the zone.

(2) The forces induced by the soft reduction zone must not affect the integrity of the existing machine segment frame now adversely affect the fatigue life of the support rolls.

(3) The internal cracking of the billet must be avoided.

The sampling is made in soft reduction section during casting. **Figure 4** shows the solidification of the billet, and there is a little liquid steel still.

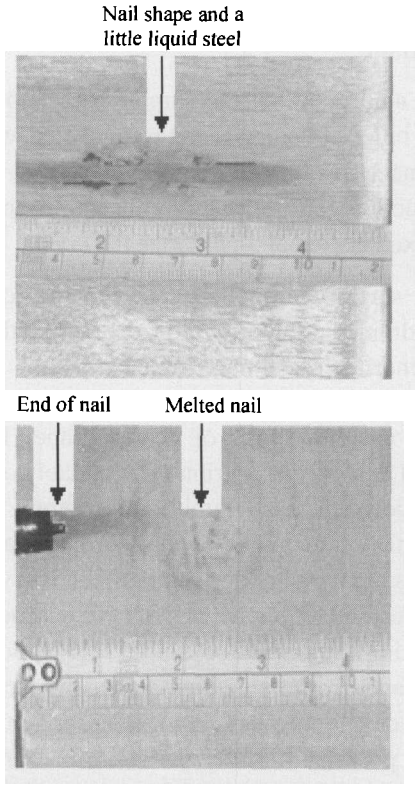

Figure 4 Solidification of the billet in soft reduction section.

The specifications are based on the experiments and must be decided as follows: (1) Casting speed, which determines the location relationship of the solidifying part and rolls; (2) The total reduction amount; (3) Reduction amount in each set.

It has been found that the related position of rolls and the liquid hard hull have been the most important factors of internal cracking. In addition, if soft reduction is applied too late, then it will have no influence on the internal quality improvement; and if soft reduction is earlier than expected, then cracking occurs. Under the latter condition, central segregation will accompany cracking.

3 Metallurgical evaluation of soft reduction

(1) Hot acid pickling method. First put the processed samples into the solution (50vol% HCl and 50vol% H_2O) with the temperature of 70°C. And after the predetermined time, clean the surface until it is dry, then observe the tri-region structure and other defects [7].

(2) Sulfur print method. Stick the printing paper that has been soaked in acid to the processed sample. Sulphides in steel and sulphuric acid react to generate hydrogen sulphide, and then sulphide reacts with silver bromide on the printing paper to form silver sulphide which then deposits on the printing paper.

4 Application of soft reduction to billets

4.1 Tri-region structure by means of hot acid pickling method

After acid pickling, the samples are photographed and the billet structure is micro-analyzed with Leica micro-image machine. As can be seen from the result, soft reduction can noticeably enhance the percentage of equiaxed crystal and pulverize the crystal grains.

From surface through center, the macro-structure can be divided into three zones [8], *i.e.* the chilled layer, dendrite crystal and equiaxed crystal. Generally speaking, the equiaxed zone has a very compact structure and large area of crystal plane. The inclusions and defects are distributed separately and the directions between crystal grains are different from each other. Thus, it acquires well-distributed and stable properties and has no orientation tendency. But for dendrite crystal, it has great orientation tendency and bad working conditions, so central segregation, central porosity and central cracking can easily occur. Therefore, the development of dendrite crystal must be necessarily prevented during the solidification of metal and alloys, so as to amplify the equiaxed zone and pulverize the equiaxed crystal.

Figure 5 has given the tri-region sketch of the chilled layer, dendrite crystal area and symmetrical crystal area. The method is: draw four lines in the horizontal and vertical directions respectively, and then construct the coordinate to get the length of symmetrical crystal area L3 and the total length of the three areas L1+L2+L3. Then calculate the average of these lengths and finally get the percentage of symmetrical crystal area to the total area.

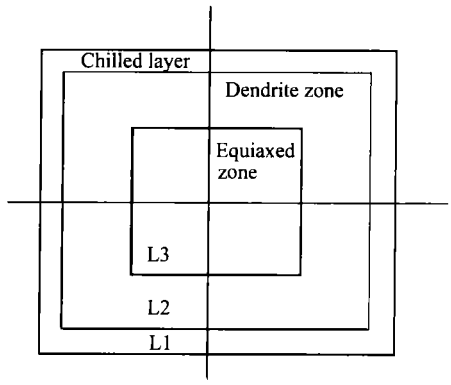

Figure 5 Schematic diagram of the billet tri-region structure.

As shown in **figure 6**, with the treatment of soft reduction, the percentage of symmetrical crystal area has been increased greatly, so the mechanical properties can be improved.

It can also be seen from figure 6 that with the application of soft reduction, the percentage of equiaxed crystal is really enhanced and thus better mechanical properties are obtained.

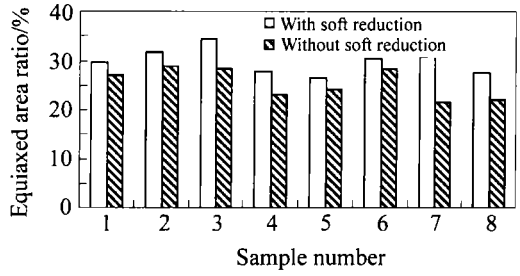

Figure 6 Equiaxed ratio of billet samples.

4.2 Internal quality

The central compactness is the main factor affecting the internal quality. However, the defects that influence the central compactness are central cracking, central segregation, porosity as well as non-metallic inclusions at the center of the billet. The technique of soft reduction can effectively lower the central segregation and central porosity and thus improve the qualities and properties of steel, especially for medium-carbon and high-carbon steel.

The chemical segregation of [C], [P], [S] in the billet was checked with sampling method (**figure 7**). There is no obvious difference of chemical composition in the billet section with and without soft deduction, because the low carbon steel with low [P] and [S] content is produced.

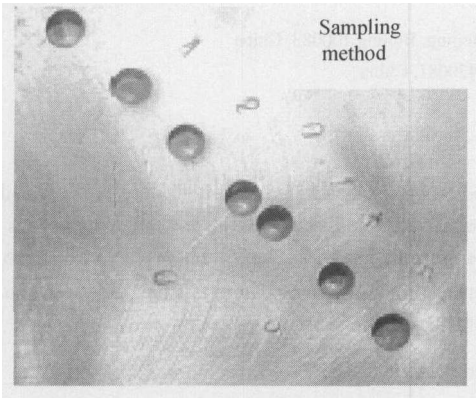

Figure 7 Sampling method in the billet.

In order to examine the effect of using soft reduction in billet casting, the macro-examination of billets are made. One of the test results is shown in **figure 8**. It indicates that the internal quality of the billet has been improved with the application of soft reduction.

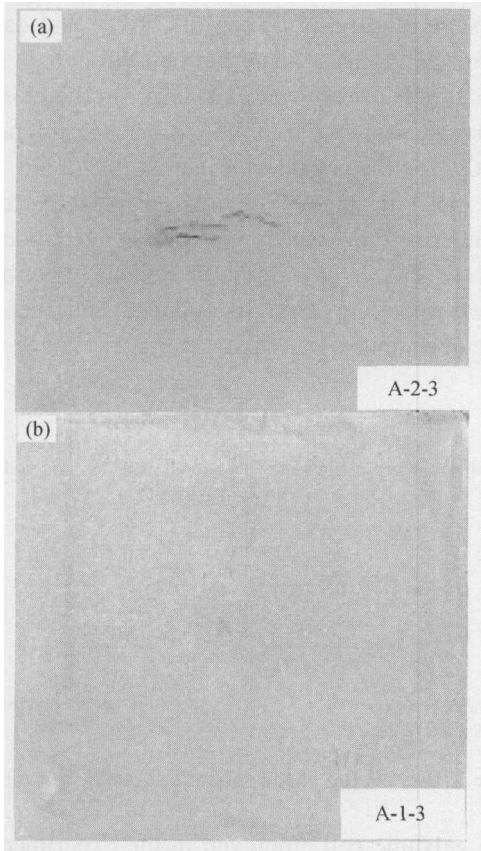

Figure 8 Macro-examination of billets: (a) without soft reduction; (b) with soft reduction.

5 Conclusions

(1) Soft reduction technique can enhance the percentage of equiaxial zone. Compared with the billets without soft reduction, the percentage of equiaxed crystal is increased by 3%.

(2) Soft reduction technique can prevent the forming of central segregation and central porosity, so as to improve the internal quality and the mechanical properties of billets.

(3) Soft reduction technique can reduce the chemical segregation at the centerline, but the effect is not obvious when low carbon steel with low [P], [S] contents is produced.

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