The formation mechanism of the line segregation in twin-roll casting (TRC) 3003 aluminium alloy

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Abstract. The formation mechanism of the line segregation in twin-roll casting (TRC) 3003 aluminium alloy was investigated. Results revealed that line segregations exhibited in the as-cast microstructures of 3003 TRC strips, depending on the different electromagnetic parameters, the position of the line segregations appeared at the center, lower, upper layers of the strips. The formation of the line segregations took place during the solidification, alloying elements were pushed towards and gathered at the center line and the resulted in the formation of the center line segregation. The dual-wave interference was the reason the changes of the position of the line segregation, when the weakened zone of the dual-wave interference appeared at the lower or upper layer of the melts, the position of the line segregation changed accordingly, when the weakened zone of the dual-wave interference appeared at the center line, the line segregation diminished.

1. Introduction

Twin-roll casting (TRC) is a technique of which cast strips are produced by a combined process of casting and rolling [1, 2, 3]. Despite TRC possesses advantages of low production costs [4, 5] and high cooling rates that refines the microstructures [6, 7], macro segregations are often inevitable during TRC [8, 9, 10]. Center-line segregation appears in the TRC strip and bring negative influences on the mechanical properties and corrosion resistance of the sheet [11].

In the study carried out by You et al. [12], 3003 aluminium alloy was produced via TRC, in which typical center-line segregation was observed. By generating electromagnetic on the solidification field, the position of the center-line segregation moved toward upper-surface or bottom surface. However, no detailed explanation was provided.

In this study, the phenomena of center-line segregation in the study of You is demonstrated. Based on the electromagnetic control of TRC process, the detailed explanation of the formation of center-line segregation and the position change of center-line segregation was provided. The emphasis of this study was placed on the effect of wave interference on the center-line segregation in TRC aluminium alloys.
2. Experimental
3003 alloy was prepared by You et al. [14], the parameter in detail was as follow. The casting was conduct using a horizontal twin roll casting equipment built by EPM of Northeast University, and the roll 500 in diameter and 500mm in length, the maximum rolling speed was 7m/min, maximum rolling force was 70kN. The pulse power supply used in the experiment is SPMD series pulse power supply, with the model of ys9000-151000, specification 1000A/15V, input voltage 380V, input current 15A AC, output voltage 0~15V and output current 0~1000A. During the experiment, the lead out wires were respectively connected to the aluminum liquid in the launder and the outlet plate. The required parameters are obtained by adjusting. The peak values of pulse current used in this experiment are 300A and 200A. The excitation current of this experiment is 250A and 200A. The casting temperature was 703~710℃, and strip was obtained with thickness of 6mm. Microstructure observation was performed using optical microscope.

3. Results and discussion

3.1. Microstructures of the 3003 strip produced by TRC
The microstructures of the TRC 3003 strip are shown in figure 1. In general, elongated grains in the strip was observed under all the electromagnetic conditions, this is due to the rolling force performed during TRC, resulting deformation of the strip, and the deform structure was retained in the strip. Besides, a very unique feature, line segregations were observed along with the rolling direction, as is shown in figure 1 (a), (b) and (c). Under the condition of IE=300A and IM=250A (figure 1(a)), the line segregations was placed at the near center line position, the line segregation exhibited not perfectly straight, but with the curved and forked morphology. When the parameter switched to IE=200A and IM=250A, the line segregations was moved towards lower surface of the strip (figure 1(b)), and the line segregation shows the morphology with straighter and thinner shape, compare with that of figure 1(a). When the parameter changed as IE=200A and IM=200A, the line segregation appeared as the similar morphology as that of figure 1(b), however, the position of the line segregation moved to the upper layer near the surface (figure 1(c)). As the parameter was set as IE=200A and IM=15A, no line segregation appeared in the microstructures (figure 1(d)), which indicated that the line segregation had been diminished by the electromagnetic field in this condition.

![Figure 1. Microstructures of the 3003 strip of produced by TRC under different electromagnetic parameters conditions: (a) IE=300A IM=250A, (b) IE=200A IM=250A, (c)IE=200A IM=200A, (d)IE=200A IM=150A.](image)
3.2. Formation mechanism of the line segregations

In general, the formation of eutectic and its size and fraction was closely related to the solidification conditions [12]. The line segregations was formed when solution atoms in the melt was gathered in the front of the solid/liquid interface, which resulted in more alloying elements reacted and formed eutectics. For the TRC process (figure 2), solidification took place at the roll surface as the melt encountered the rolls. Liquid zone, mushy zone and deformation zone were displayed in the TRC process. Along with the solidification process, alloying elements were pushed toward the center line of the solidification, resulting in the alloying elements were gathered in the front of liquid/solid interface. Consequently, the center line segregation formed and retained in the strip of 3003 alloy (figure 1(a)).

![Figure 2. Line segregations interfered by the electromagnetic field.](image)

In the experimental, the electromagnetic field was applied during TRC. Theoretically, one columns of simple harmonics (figure 3(a)) could be generated by the electric current in the melt of alloy. However, in the actual condition the dual-wave interference might occur (figure 3(b)).

![Figure 3. Schematic of (a) simple harmonics and (b) dual-wave interference.](image)

When the dual-wave interference took place, strengthened area weakened area were arranged alternately. In the TRC solidification area, the alloying elements in the strengthened area were tend to be expelled to the weakened areas. For the condition of figure 1(b), in which the position of the line segregation moved to the lower layer near the surface, the weakened zone was at the lower position of the solidification region (figure 4(a)); while at the condition of figure 1(c), in which the position of the line segregation moved to the upper layer near the surface, the weakened zone was at the upper position of the solidification region (figure 4(b)). When the weakened zone was exactly at the center line of the solidification (figure 4(c)), the strengthened zone broken the center line segregation of the alloying elements, and resulted in the diminishment of the center line segregation in the as-cast microstructures (figure 1(d)).
4. Conclusion
1. Line segregations exhibited in the as-cast microstructures of 3003 TRC strips, and depending on the different electromagnetic parameters, the position of the line segregations appeared at the center, lower, upper layers of the strips.
2. The formation of the line segregations took place during the solidification, alloying elements were pushed towards and gathered at the center line and the resulted in the formation of the center line segregation.
3. The dual-wave interference was the reason the changes of the position of the line segregation, when the weakened zone of the dual-wave interference appeared at the lower or upper layer of the melts, the position of the line segregation changed accordingly, when the weakened zone of the dual-wave interference appeared at the center line, the line segregation diminished.

Acknowledgments
The authors gratefully acknowledge the support of the National Natural Science Foundation of China (Grant No. 51790485), the Fundamental Research Funds for the Central Universities (No. N2007008), Nanning science and technology major special projects (No. 20201041) and the Key research and development project of Shandong province (No. 2019JZZY010401).

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