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Analysis and Control of Surface Reticular Cracks in Medium Carbon Continuous Casting Round Billet

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ABSTRACT

In this paper, the formation and characteristics of surface reticular cracks on the medium carbon continuous casting round billet were analyzed by the optical and scanning electron microscope (SEM). The results show that the cracks near the surface of the round billet are distributed along the austenite grain boundary. The coarse austenite grains, the film-like pro-eutectoid ferrite along grain boundaries and the enriched phase of [As] are the main causes for the formation of reticular cracks. The temperature of the casting steel in the metallurgical process is so high, which increases the content of residual [As] element to great extent, as a result the cooling of the round billet, becomes uneven. The non-uniform cooling directly leads to coarse austenite grains, the accumulation of [As] on the grain boundaries and the formation of pro-eutectoid ferrite. On these bases, the improvement measures to control the surface reticular crack are put forward and effectively implemented to achieve remarkable results.

Keywords: *Surface Reticular Cracks; Coarse Austenite Grains; [As] Enrichment Phase; Pro-Eutectoid Ferrite; Continuous Casting Round Billet.*

INTRODUCTION

The cracks occur on the surface of the slab during the continuous casting process, and to find the factors responsible for the formation of surface cracks are quite complicated[1,2]. The classification, morphology, factors affecting and formation mechanism of surface cracks in continuous casting slab have been studied in detail in domestic and foreign literature [3,4]. During the production of medium carbon continuous casting round billet in a steel plant, the irregular reticular cracks appear on the surface of the round billet. The appearance of reticular cracks has a certain impact on the post-rolling products which is very likely to cause forging cracks, which seriously affects the quality and manufacturing cost. In this paper, the surface reticular cracks appearing on the continuous casting round billet are comprehensively analyzed. The characteristics and formation mechanism of the reticular cracks are studied and corresponding improvements for controlling the surface reticular crack are put forward in seek of effective implementation, which is used in the industrial application and have good theoretical as well as practical application value.

PRODUCTION PROCESS AND TECHNICAL PARAMETERS

The production process of medium carbon continuous casting round billet involves the converter, LF refining, vacuum furnace treatment and round billet continuous casting. The content range of the main elements of steel grade is shown in Table 1. The main technical parameters of round billet continuous casting machine are shown in Table 2.

Table1. *Content range of major elements in medium carbon steel (%).*

C	Si	Mn	P	S	Cr	Al
0.58~0.64	0.20~0.37	0.70~0.80	≤0.020	≤0.015	0.15~0.25	≤0.015

EXPERIMENTAL

In order to investigate the formation and characteristics of surface reticular cracks on the medium carbon round billet, the following steps were used for sampling and analysis.

1. For a typical reticular crack region, the round sample with a thickness of about 30 mm was taken and etched with hot acid in an aqueous

solution of 1:1 hydrochloric acid in order to reveal the macroscopic morphology. The etching temperature and time were about 75 °C and 30 minutes.

2. A sample about 20 mm × 20 mm × 20 mm was taken from the area of reticular cracks and the test surface of the sample was polished to observe the microscopic characteristics and metallographic analysis of the reticular crack. At the same time, the sample was etched with 4% nitric acid to observe the micro-morphologies near the surface of the crack.

3. The metallographic specimens were prepared and the compositions of the inclusions, as well as the content of the residual element in cracks, were analyzed with scanning electron microscopy (SEM), energy dispersive spectrum analysis (EDS) and scanning electron probe analysis of residual element.

Table2. *Main technical parameters of round billet continuous casting machine.*

Project	Parameters
Model	3 points & 5 stands arc straightening
Round billet size specification	∅380mm/∅450mm
Number of strands	3 strands
Arc radius	12m
Casting speed	0.40~0.60 m/min
Capacity of tundish	28t
Secondary cooling zone Electromagnetic stirring	4 sections air mist cooling mold- electromagnetic stirring

RESULTS AND DISCUSSION

Characteristics of Surface Reticular Cracks

The surface cracks in the original state of the round billet are difficult to find, after etching with hot acid, the cracks are clearly presented which are distributed in a fine network. The macroscopic feature of the surface cracks is shown in Fig. 1, while the morphology of internal distribution of the reticular cracks is shown in Fig. 2, which illustrates that the crack is distributed in one dimension near the surface of the round billet and its depth is in between 200 μm to 5.25mm.

The microscopic morphology of crack depth is shown in Fig. 3.

Fig1. *The macroscopic feature of surface cracks.*

Fig2. *Macroscopic distribution characteristics of reticular crack*

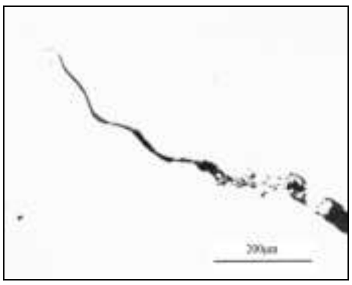

Fig3. *Microscopic morphology of crack depth.*

Fig 4 shows the microscopic metallographic structure of the typical crack region. It can be seen from the figure that the cracks are distributed along the austenite grain boundary and are extended along the intersection of these boundaries.

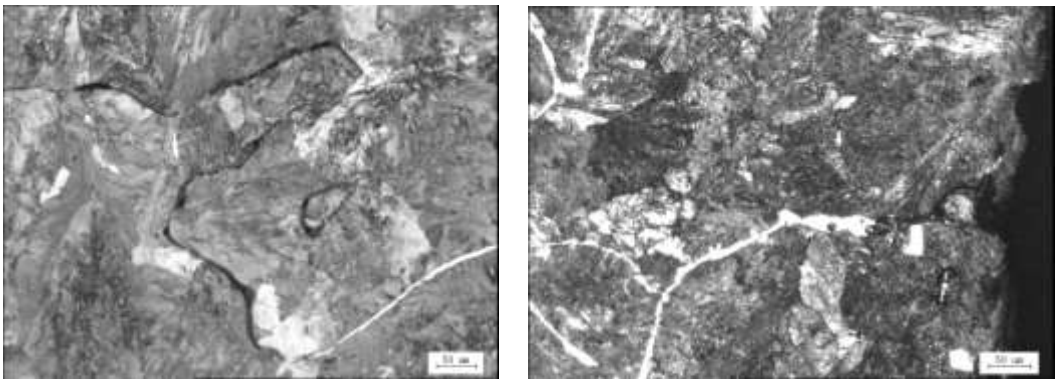

Fig4. *Microscopic metallographic structure of the crack region.*

The results of scanning electron microscopy (SEM) and energy spectrum analysis (EDS) of the crack region are shown in Fig. 5, which indicated that the crack is filled with inclusions and its composition mainly have the silicate components which contained a certain amount of F and a small number of elements such as K and Na. The compositions of the mold fluxes and the inclusions in the crack are shown in Table 3. The composition of the inclusions in the crack was substantially consistent with the composition of the mold fluxes and it was concluded that these inclusions originate from the mold fluxes.

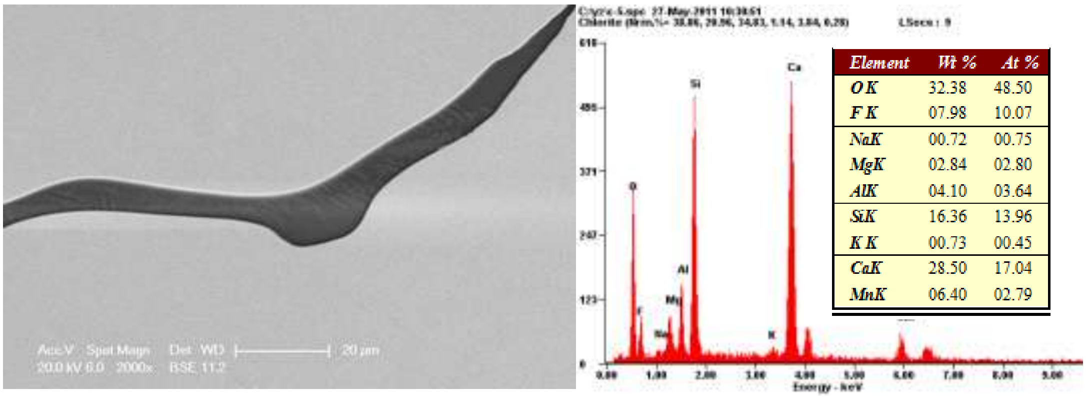

Fig5. *Scanning electron microscopic and energy dispersive spectroscopic analysis of inclusions in the crack.*

Table3. *Composition of mold fluxes and inclusions in the crack (%).*

Ingredient	CaO %	SiO2%	Al2O3%	F%
Mold slag	37.43	47.11	7.11	8.35
Inclusions in the crack	44.10	38.59	8.49	8.82

Analysis of Surface Reticular Cracks

Enrichment of [As] Element in the Crack Region

During the cooling and warming process of the round billet, the surface oxidation occurs continuously and the [As] element which is not easily oxidized was deposited in the interface layer between the iron oxide scale and the steel substrate. When the concentration exceeds the upper limit of solubility in the steel, [As] and other residual elements formed a molten composite phase of a low melting point [6]. The molten phase can easily penetrate into the grain boundary. Therefore, the [As]-rich phase increased on the austenite grain boundary, the continuity of the grain boundary was destroyed, and the binding force of the grain boundary was drastically reduced [7,8]. As the original content of [As] in the steel increases, the effect will also be more prominent. Fig. 6 shows the distribution of the [As] element in the crack region by the scanning electron micro probe, in which (a) is a photomicrograph of the defective region and (b) is a cloud image of the [As] element distribution. The [As] element has a certain degree of enrichment in the crack region and its enrichment directly leads to a sharp deterioration of the steel thermo-plasticity.

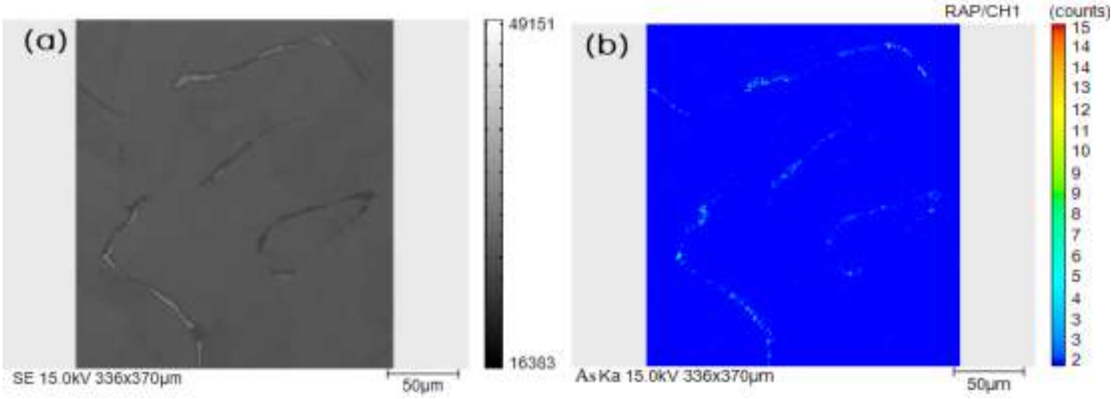

Fig6. *Distribution characteristics of [As] element in the crack region.*

The content of residual [As] element in steel is directly related to the degree of [As] enrichment and penetration on the grain boundaries. If the [As] content in the steel increases, the [As] enrichment and segregation become more significant, the effect on the continuity and bonding force of the austenite grain boundary will be more obvious and the probability of surface reticular crack increases. In the industrial practice, the content of [As] element in the round billet with surface reticular crack reaches 0.015%, which is obviously higher than normal level. It increases the probability of occurrence of surface reticular cracks, at the same time the [As] element enriched at the grain boundary, which will delay the transformation process from γ phase to α phase, thereby the probability of producing film-like pro-eutectoid ferrite on the prior austenite grain boundary increases [10].

Coarse Austenite Grain

Figs. 7 and 8 show the typical metallographic structure and the distribution characteristic of the austenite grain size. The grains of the solidified structure are coarse with the maximum and minimum size of 2000μm and 400μm respectively. The proportion of austenite grain size above 1000μm is 90%. The austenite grains are coarse with relatively weak grain boundaries, which also weaker the bonding force between the grains.

The micro-cracks distributed along the grain boundary can easily generate under the action of small stress. The coarse austenite grains are the main cause of surface intergranular cracks. Professor Rain Dippenaar of Wollong University in Australia referred to austenitic grains larger than 1000μm as "Blown Grain" and indicated that coarse austenite grains play a decisive role in the formation of surface cracks [5].

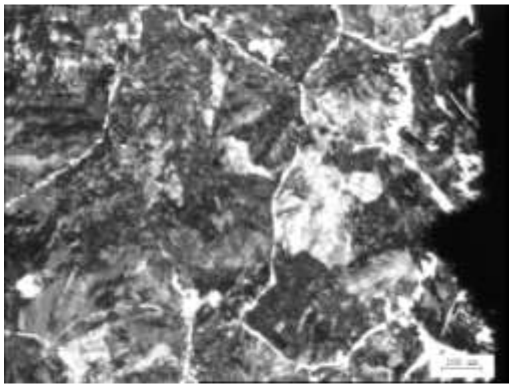

Fig7. *The microstructure of defective sample.*

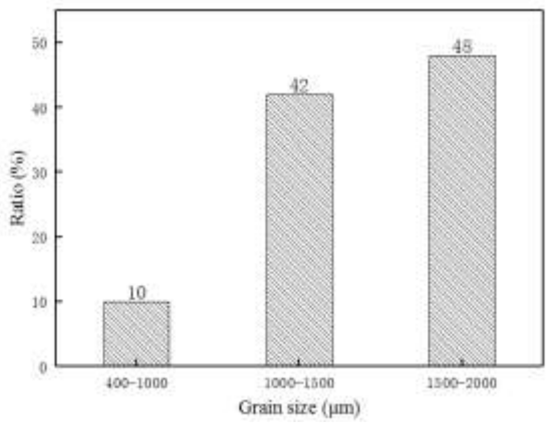

Fig8. *The grain size distribution of the defective sample.*

The austenite grain size in the solidified structure of round billet is directly related to the temperature of the casting steel and the cooling uniformity of round billet. The high degree of superheat in the casting molten steel leads to the low thickness of the solidified shell, the development of the columnar crystal, and the coarsening of the structure. The non-uniform cooling results in uneven growth of the shell and also the shrinkage of the shell to form an air gap, causing the surface to warm up, when the temperature rises to 1300℃ or higher, austenite grains continue to aggregate and grow up even several times than primary grains size. The high superheat of the casting steel and the uneven cooling leads to coarse austenite grains [9]. In the industrial practice, the round billets with surface reticular cracks are found, in which the superheat of the tundish steel is too high as reaching about 40-50 °C, as shown in Fig. 9.

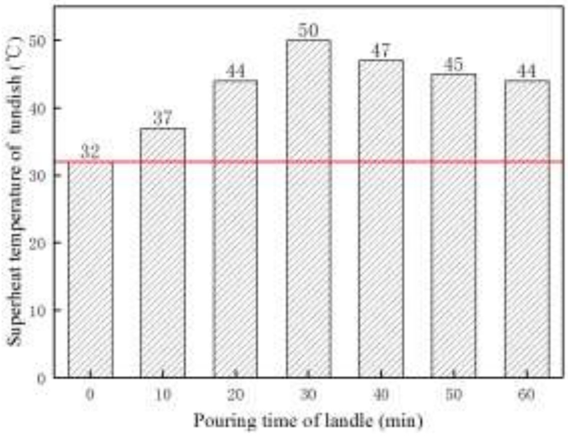

Fig9. *Superheat degree of molten steel in the casting process.*

Pre-Eutectoid Ferrite Precipitated along the Grain Boundary

Fig.10 is a typical metallographic structure of the crack region in which film-like pro-eutectoid ferrite is precipitated on the austenite grain boundary. Since the strength of α-Fe is only 1/4 than that of γ-Fe, it was easy to lead the stress concentration under the action of thermal or deformation stress, as a result the grain boundary became brittle and the micro-cracks were formed along with it.

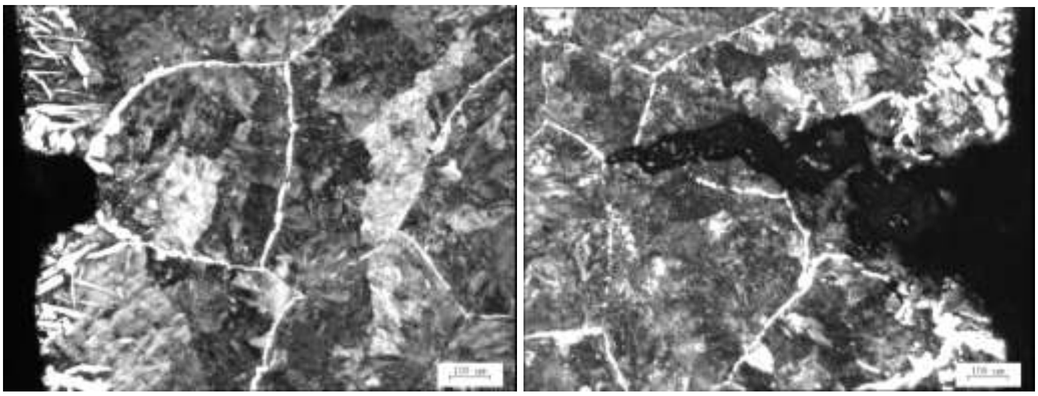

Fig10. *Typical metallographic structure of the crack region.*

Control Measurements for the Surface Reticular Crack of the Round Billet

According to the characteristics of the surface reticular crack and the causes of its formation, specific control measurements were formulated: (1) Establishment of a reasonable temperature control system and strictly control the superheat of the casting steel in the range of 25℃~ 35℃; (2) Strengthen the management of molten iron and scrap resources, control the content of [As] in the steel within 0.008%; (3) Select suitable mold powder, maintain the viscosity and fluidity of mold fluxes and ensure that the lubrication and cooling of the shell is uniform. (4) Reduce the cooling strength of the secondary cooling zone, improve the distribution of cooling water in the secondary cooling zone and improve the uniformity of cooling of the round billet, as to avoid the repeated phase transition of γ→α→γ due to uneven cooling and surface reheating of the round billet. Through the effective implementation by the above control measurements, the surface reticular cracks in the medium carbon continuous casting round billet have been completely solved.

CONCLUSIONS

1. The surface reticular crack was distributed along the grain boundary near the surface of the round billet and the depth of the cracks was in between 200μm and 5.24mm. At the same time, the crack was filled with inclusions from the mold fluxes.
2. The size of austenite grain is related to the temperature of the casting steel and the cooling uniformity of the round billet. The high superheat and the uneven cooling lead to coarse austenite grains.

3. The main reason for surface reticular crack on the medium carbon round billet is that the austenite grains are coarse with film-like pro-eutectoid ferrite and the enrichment phase of the [As] on the austenite grain boundary. Therefore, the bonding force of the grain boundary was further reduced and the thermo-plasticity of the round billet was rapidly deteriorated.
4. The content of residual [As] element in steel is directly related to the degree of [As] enrichment and penetration on the grain boundaries. In the industrial practice, the content of [As] element in the round billet reaches to 0.015% or above, which increases the occurrence probability of surface reticular cracks. By controlling the reasonable temperature of molten steel, the content of residual [As] element in steel and the uniformity of continuous casting cooling, the surface reticular cracks on the medium carbon continuous casting round billet can be reduced.

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