Reasons for the Formation of Tissue Defects in Continuous Casting Low Alloy Extra-Thick Plates and Countermeasures

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Abstract. Scanning electron microscopy and electron probe were used to observe the internal defects of continuous casting low alloy extra-thick plates. The results show that there is Mn segregation, MnS segregation, inclusions and Al2O3 inclusions in 100mm continuous casting low alloy extra-thick plates; The center is loose and the microcracks are accompanied by the central segregation and inclusions. These defects greatly damage the mechanical properties of the product. In order to reduce these defects, the method of controlling sulfur and calcium is used in the smelting process to reduce the formation of MnS; controlling the moisture and combined water absorbed by the steelmaking materials, and reducing the hydrogen content in the molten steel and the formation of hydrogen atoms to reduce cracking of the steel sheet.

1. Introduction
With the development of China's heavy industry, the amount of steel used in large equipment manufacturing, mechanical engineering, offshore platforms, large molds, etc. continues to increase, and the demand for large single heavy plates has increased dramatically year by year. Since the ultimate thickness of the continuous casting slab for producing extra-thick plates is 450 mm, the compression ratio of extra-thick slabs having a thickness of 100 to 150 mm or more is less than 4.5. Due to the insufficient compression ratio, the defects in the steel slab are difficult to heal by pressing, and the yield of the production flaw detection is lowered. Due to the presence of flaw detection, the steel plate cannot meet the demand for high-strength steel. In order to deal with the impact of insufficient compression ratio on the production of special thick plates, this paper attempts to study the formation and derivation of flaw detection defects in continuous casting low alloy extra-thick plates from the perspective of defect formation. This paper mainly discusses the confirmation of the steel plate flaw in the thick steel plate ultrasonic crack detection system. From a certain size, defects of this type can be detected by ultrasonic inspection before delivery. The work was to resolve some problems which puzzled automatic ultrasonic flaw detecting [1-8].

2. Experimental procedure
Continuous casting slab production process as follows: mechanical stirring→hot metal desulphurization → converter smelting→LF refining→VD(vacuum degassing)→protection pouring→the slab slow cooling→surface cleaning straightening→heating→3800mm plate mill→slow cooling→testing→heat treatment→finishing external examination→performance testing→ultrasonic testing→storage.
After ultrasonic testing, those unqualified thick steel plate to be used as detection. The exact location of the defect was found by the testing machines. In the defect site, the sample including all the defection were prepared. When cutting the sample, reconfirmed its defect depth to ensure its facets is the result of proven defects, and then use the microscope 200MATAxiovent section metallographic examination, and then using S3400 II scanning electron microscopy and Apollo XV energy dispersive spectroscopy performed for abnormal tissue further observation.

3. Results and discussion

3.1. Manganese segregation

Plates with flaw detection are sampled for observation Sampling and observation. The slabs used to produce steel sheets are produced by continuous casting process, and all the indicators meet the process requirements. The steel sheet was sampled near the head, and the flaw detection of the steel sheet showed a point defect. From the electron microscopy, there is a heavier center segregation in the center of the steel plate, and there are discontinuous microcracks in the segregation zone. There are more granular bainite structures and coarse pearlitites along the crack, and the positive segregation zone of Mn. Figure 1 shows the metallurgical structure of the slab in TEM. The sample was observed by projection electron microscopy and found to have banded tissue defects containing manganese segregation. Sampling by the side of the crack for energy spectrum analysis (as shown in Figure 2), found that the manganese content near the defect exceeded other positions, as shown in Table 1, the Mn content at the point is 2.74%, and the Mn content at the defect-free site is 1.82%. Therefore, the banded structure is related to the microsegregation factor of manganese. Formation of banding is related to microsegregation of manganese in the ingot and hot band; it is found that the main cause of manganese segregation is that manganese segregation caused by unbalanced crystallization during casting is not effectively eliminated. Table 2 shows the elemental composition of the defect.

Figure. 1 microstructure of the plate by TEM

Figure. 2 The energy spectrum of the sample defect
Table. 1 the mass percent of chemical composition

|         | Si  | Mn  | Fe  |
|---------|-----|-----|-----|
| near the crack | 0.62 | 2.74 | 96.64 |
| No crack    | 0.49 | 1.82 | 97.68 |

Table. 2 Inclusion Composition at Crack

| Element | Wt% | At% |
|---------|-----|-----|
| S       | 37.11 | 50.28 |
| Mn      | 62.89 | 49.72 |

The first set of samples was observed as MnS point defects (see Figure 1). The result observed in the second set of samples is a linear defect (see Figure 3), which is the crack. Steel plates often contain a large amount of chain-like manganese sulfide inclusions. These inclusions contained in the slab form a crack source for the steel sheet. After energy spectrum analysis, these black-grain defects are segregation bands composed of ferrite of aggregated distribution of manganese sulfide inclusions. The structure within the segregation line is composed of upper bainite, ferrite and pearlite. The entire matrix structure is composed of ferrite, bainite, and pearlite. There are long discontinuous microcracks on the segregation line. There is a long strip of MnS in the crack source, and there are a large number of long strips of MnS aggregates, and multiple cracks are arranged in parallel. According to the analysis, there are many long strips of MnS inclusions in the center of the sample. These inclusions become a "trap" of hydrogen and become a source of cracks under the action of tissue stress. Microcracks are the direct cause of unqualified flaw detection of steel sheets. Figure 4 shows the sample defect spectrum.

Figure. 3 microstructure of the plate by TEM

Figure. 4 The energy spectrum of the sample defect
Therefore, the formation of manganese sulfide can be reduced by controlling the content of sulfur, reducing the formation of manganese sulfide, increasing the content of calcium and increasing the formation of calcium sulfide [9-11].

3.2. Al2O3 inclusions
The Al2O3 inclusion in continuous casting low alloy extra-thick plates was observed and analyzed by means of TEM and the energy spectrum. Figure 5 shows a TEM image of the flaw detection sample. The defects displayed by the ultrasonic flaw detection instrument are point defects. The depth of the point defects is 49 mm in the longitudinal direction of the steel sheet, respectively. Electron microscopy showed (Figure. 6) that there were microcracks in the flaw detection and there were inclusions in the crack. After energy spectrum analysis, the inclusion component here is Al2O3 (see Tables 3 and 4). Therefore, Al2O3 inclusions become a source of cracks during rolling. This crack source is the main cause of the flaw detection of the steel plate.

Calcium treatment (feeding silicon calcium wire) is applied to excess aluminum deoxidized steel to change the morphology of Al2O3. After calcium treatment, the Al2O3 inclusions become anorthite (CaO. Al2O3.SiO2) with a melting point of 1200-1400 °C, which is easy to float in the molten steel. This method is called light calcium treatment [12-13].

Figure. 5 Microstructure of the slab by TEM

![Microstructure of the slab by TEM](image)

Figure. 6 The energy spectrum of the sample defect

![The energy spectrum of the sample defect](image)
Table. 3 the mass percent of chemical composition

| Composition beside crack | Si  | Mn | Fe |
|--------------------------|-----|----|----|
| Bainite                  | 0.45| 2.73 | 96.82 |
| Ferrite                  | 0.40| 1.71 | 97.89 |

Table. 4 Inclusion Composition at Crack

| Element | Wt% | At% |
|---------|-----|-----|
| O       | 42.60 | 55.59 |
| Al      | 57.40 | 44.41 |

3.3. Center shrinkage and segregation

The results showed that central porosity and ingot shape segregate were the major causes of the cracking. Center segregation and center porosity will seriously affect the internal slab quality for continuous casting bloom. In the late stage of solidification of the continuous casting billet, in the residual molten metal of the final solidified part, the temperature gradient is small, so that it solidifies according to the principle of simultaneous solidification, that is, many fine crystal grains appear in the molten metal, and after the crystal grains grow and are connected to each other, The remaining molten metal is divided into small molten pools that are not connected to each other. These small molten pools are not filled with liquid when further cooling and solidifying, and many fine holes are formed (as shown in Figure. 7). Figure. 8 shows the energy spectrum analysis of the shrinkage at this point. The results showed that the central porosity in the raw material were the direct reasons which the forging cracking.

Due to the selective crystallization during the solidification of the molten steel, the composition of the central part of the slab is significantly different from other areas of the slab. This phenomenon is central segregation. In addition, the bulge of the continuous casting billet will increase the degree of center segregation. Under normal circumstances, the content of each element in the central part is higher than other parts. This condition is called positive segregation; in some cases, the content of the central element is lower than other parts. This phenomenon is called negative segregation. The elements that are generally prone to central segregation are C, S, P, and the like. Due to the particularity of many special steels in the processing technology and the requirements of use, the strict requirements for the central segregation of carbon are put forward. Therefore, the central carbon segregation index is an important quality index for some special steel continuous casting billets. The shape of the central segregation is: acid etching of the cross section or longitudinal section of the continuous casting billet, the center part will show dark spots with deep corrosion, sometimes there are gray bands around the dark spots and loose.

![Figure. 7 Microstructure of the ingot by TEM](attachment:image.png)
Therefore, central segregation and porosity of billet would inherit to rolled steel. Production practice has showed that the application of static soft reduction technology can decrease carbon segregation and improve looseness state in billet central area. The dynamic soft reduction technology is the effective method to reduce and even eliminate the centerline looseness and segregation of continuous casting strands. Porosity and light segregation existed within rolled steel and the inner mechanical property is poor relatively.

4. Conclusion
1) The main reason for the detection of low alloy steel sheets with a specification of 100 mm is Mn segregation; MnS segregation and inclusion; Al2O3 inclusions; the center is loose. Usually microcracks are accompanied by central segregation and inclusions. In order to eliminate these defects 2). Therefore, by controlling the sulfur content, reducing the formation of manganese sulfide, increasing the calcium content and increasing the formation of calcium sulfide, the formation of manganese sulfide can be reduced.
3) Calcium treatment (feeding silicon calcium wire) on excess aluminum deoxidized steel, changing the morphology of Al2O3. After the calcium treatment, the Al2O3 inclusions become anorthite (CaO·Al2O3·SiO2), melting point is 1200-1400 °C, and are removed by floating in molten steel.
4) The application of static soft reduction technology can reduce carbon segregation and improve the loose state of the billet central area. Dynamic soft reduction technology is an effective method to reduce or even eliminate the looseness and segregation of the continuous casting slab centerline.

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