Effect of Slag Composition on Non-metallic Inclusions for Gear Steel during LF Process

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Abstract. Effect of slag composition on non-metallic inclusions for gear steel during LF process is investigated in this paper. It is found that with CaO-Al2O3-MgO slag and low SiO2 content in the slag, non-metallic inclusions in liquid steel can be transformed into tiny globular CaO-MgO-Al2O3-CaS complex inclusions during LF refining process, which is helpful to improve the quality of gear steel.

Introduction
Non-metallic inclusions in steel have great influence on fatigue performance of high strength gear steel. The larger, distortion-free, irregular and angular shaped inclusions may actually be more harmful for fatigue performance of steel[1]. After LF refining treatment, most of non-metallic inclusions in liquid steel are transformed into tiny globular inclusions, which is helpful to improve the quality of steel[2]. The different types of LF refining slag will transform non-metallic inclusions differently, so how to choose the refining slag is very important.

LF Refining Slag
The general smelting process of gear steel is that charging SiMn ferroalloy when BOF tapping and feeding Al line in LF refining process for deoxidization. LF refining slag is CaO-SiO2-Al2O3 slag (Al2O3~15%). New smelting process for gear steel in this paper is that charging Al for deoxidization directly, LF refining slag is CaO-Al2O3-MgO slag with less SiO2 content. The alkalinity CaO/Al2O3 is between 1.4 to 3.2.

The two kinds of slag composition listed above is used in this paper, and steel samples is taken at early stage (15 minutes after charging deoxidizer) and the end of LF refining process. Steel samples were polished and the chemical composition and profile of inclusions in steel samples were analyzed by SEM-EDS.

The Transformation of Non-metallic Inclusions during LF Treatment
The CaO-SiO2-Al2O3 slag has been adopted in the LF treatment, and fig.1 shows the non-metallic inclusions of steel samples which were taken at early stage of LF refining process.
It is shown by Fig.1 that the size of inclusions is mostly smaller than 10µm at early stage of LF refining process. It is found by SEM-EDS that the inclusions consist of MgO-Al₂O₃ and part of them are circular calcium aluminate inclusions. Minority of the inclusions contain a few SiO₂.

The fig.2 shows the non-metallic inclusions of steel samples which were taken at early stage of the LF refining process when adopting the CaO-Al₂O₃-MgO slag. It is shown that the size of inclusions is mostly smaller than 10µm after high basicity slag washing, strong deoxidizing and argon bubbling process. It is found by SEM-EDS that the inclusions mainly consist of Al₂O₃ and part of them contain Cr₂O₃ and MnS.

The gear steel smelting experiments show that the floating degree of the inclusions in the liquid steel adopting the CaO-Al₂O₃-MgO slag is obviously higher than that in the liquid steel adopting the CaO-SiO₂-Al₂O₃ slag at early stage of LF refining process in fig.3. At that time, most of the deoxidation products Al₂O₃ transform into MgO-Al₂O₃ inclusions. Due to the short reaction time
between liquid steel and slag, CaO in the slag is not reduced. As a result of this, the inclusions contained a few CaO. Despite adopting the high basicity slag washing and argon bubbling process, Al₂O₃ inclusions in liquid steel have not been transformed into calcium aluminate inclusions.

Fig.4. Non-metallic inclusions of steel samples with CaO-SiO₂-Al₂O₃ slag at the end of LF process

Fig.4 shows the inclusions in the liquid steel adopting CaO-SiO₂-Al₂O₃ slag at the end of LF process. With the SEM-EDS analysis, it is found that there are three types of inclusions: (1) MgO-Al₂O₃ complex inclusion; (2) CaO-Al₂O₃-MgO complex inclusion; (3) A few MnO-Cr₂O₃ and MnS complex inclusion.

Fig.5. Non-metallic inclusions of steel samples adopting the CaO-Al₂O₃-MgO slag at the end of LF process

Fig.5 showed the inclusions in the liquid steel adopting CaO-Al₂O₃-MgO slag at the end of LF process. With the SEM-EDS analysis, it is found that non-metallic inclusions of liquid steel mostly are transformed into tiny globular calcium aluminate and magnesium aluminate complex inclusions after LF refining process, part of which contain a few CaS.

The gear steel smelting experiments show that CaO and CaS occupy a bigger proportion in the inclusion of liquid steel adopting CaO-Al₂O₃-MgO slag than that in the liquid steel adopting CaO-SiO₂-Al₂O₃ slag. After LF refining, CaO and CaS content in inclusions increase and is sphere shaped. The CaO/Al₂O₃ rate of the calcium aluminate inclusions adopting CaO-Al₂O₃-MgO slag gradually is close to 1, which is located at the low-melting-point region of the CaO-Al₂O₃ phase.
diagram[3], while the CaO content of the calcium aluminate inclusions adopting CaO-SiO$_2$-Al$_2$O$_3$ slag is around 30%.

By CaO- Al$_2$O$_3$-MgO slag, the inclusions in the liquid steel at early stage of LF refining composes of Al$_2$O$_3$ inclusions which will be transformed into CaO-MgO-Al$_2$O$_3$ inclusions by LF refining. At the end of LF refining process, most of inclusions have been transformed into tiny globular CaO-MgO-Al$_2$O$_3$-CaS complex inclusions which are helpful for the improvement of the quality of gear steel.

**Conclusions**

By comparison between two types of LF refining slag, conclusions are drawn as below.

1) At early stage of LF refining process, the floating degree of the inclusions in the liquid steel adopting CaO- Al$_2$O$_3$-MgO slag is obviously higher than that in the liquid steel adopting CaO-SiO$_2$-Al$_2$O$_3$ slag.

2) CaO and CaS occupy a bigger proportion in the inclusion of liquid steel adopting CaO-Al$_2$O$_3$-MgO slag than that in the liquid steel adopting CaO-SiO$_2$-Al$_2$O$_3$ slag.

3) At the end of LF refining process, most of non-metallic inclusions have been transformed into tiny globular CaO-MgO-Al$_2$O$_3$-CaS composite inclusions which are helpful for the improvement of the quality of gear steel.

**References**

