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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 $CaO-Al_2O_3-MgO$ slag and low SiO_2 content in the slag, non-metallic inclusions in liguid steel can be transformed into tiny globular $CaO-MgO-Al_2O_3-CaS$ 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 $CaO-SiO_2-Al_2O_3$ slag (Al_2O_3~15%). New smelting process for gear steel in this paper is that charging Al for deoxidization directly, LF refining slag is $CaO-Al_2O_3-MgO$ slag with less SiO_2 content. The alkalinity CaO/Al_2O_3 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 $CaO-SiO_2-Al_2O_3$ 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.

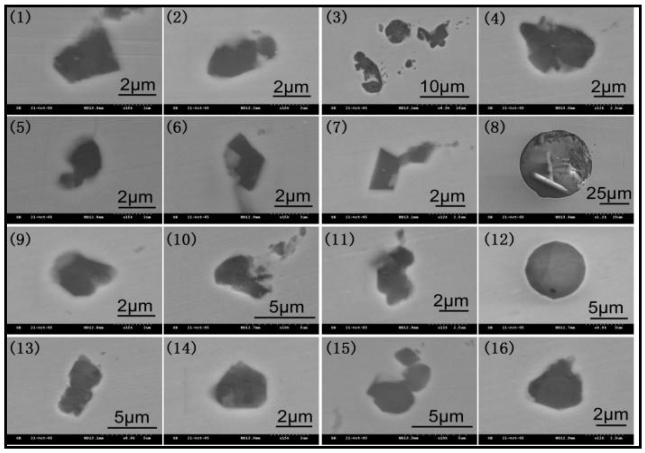


Fig.1. Non-metallic inclusions of steel samples with CaO-SiO_2-Al_2O_3 slag

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-Al_2O_3 and part of them are circular calcium aluminate inclusions. Minority of the inclusions contain a few SiO_2.

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-Al_2O_3-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 Al_2O_3 and part of them contain Cr_2O_3 and MnS.

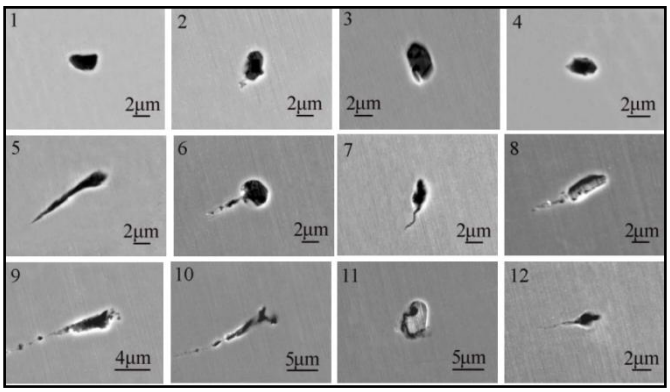
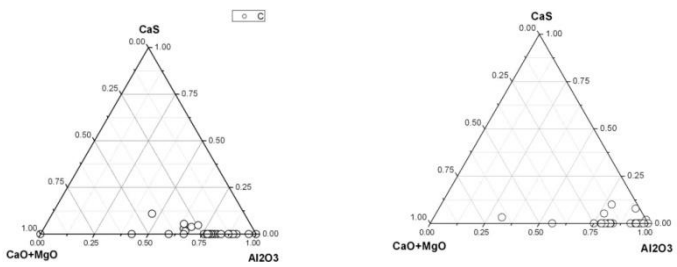


Fig.2. Non-metallic inclusions of steel samples adopting the CaO-Al_2O_3-MgO slag



(a)Inclusion Component with CaO-SiO_2-Al_2O_3 slag

(b) Inclusion Component with CaO- Al_2O_3-MgO slag

Fig.3. Comparison of Inclusion Component with different slag at early stage of LF treatment

The gear steel smelting experiments show that the floating degree of the inclusions in the liquid steel adopting the CaO-Al_2O_3-MgO slag is obviously higher than that in the liquid steel adopting the CaO-SiO_2-Al_2O_3 slag at early stage of LF refining process in fig.3. At that time, most of the deoxidation products Al_2O_3 transform into $MgO{\cdot}Al_2O_3$ 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, Al_2O_3 inclusions in liquid steel have not been transformed into calcium aluminate inclusions .

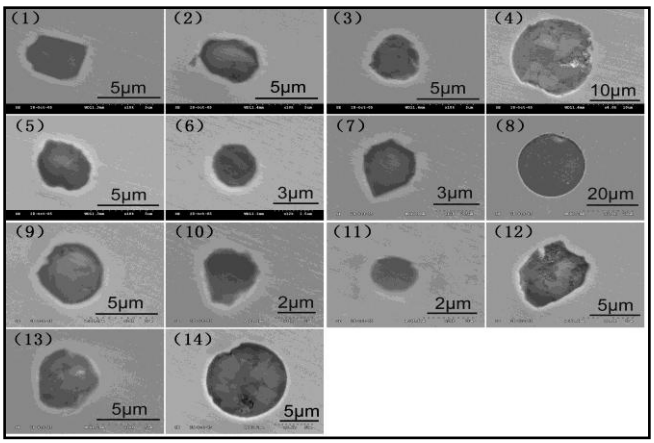


Fig.4. Non-metallic inclusions of steel samples with $CaO-SiO_2-Al_2O_3$ slag at the end of LF process

Fig.4 shows the inclusions in the liquid steel adopting $CaO-SiO_2-Al_2O_3$ slag at the end of LF process. With the SEM-EDS analysis, it is found that there are three types of inclusions: (1) $MgO-Al_2O_3$ complex inclusion; (2) $CaO-Al_2O_3-MgO$ complex inclusion; (3) A few $MnO-Cr_2O_3$ and MnS complex inclusion.

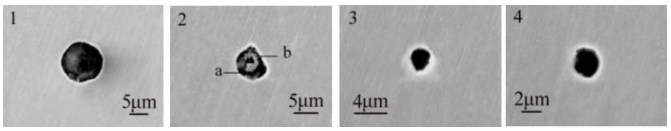
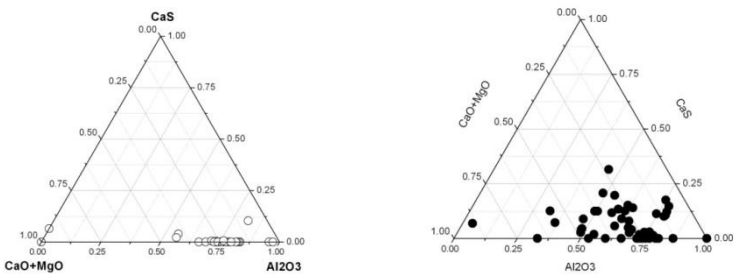


Fig.5. Non-metallic inclusions of steel samples adopting the $CaO-Al_2O_3-MgO$ slag at the end of LF process

Fig.5 showed the inclusions in the liquid steel adopting $CaO-Al_2O_3-MgO$ 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.



(a) $CaO-SiO_2-Al_2O_3$ slag (b) $CaO-Al_2O_3-MgO$ slag

Fig.6. Comparison of Inclusion Components with different slag at the end of LF treatment

The gear steel smelting experiments show that CaO and CaS occupy a bigger proportion in the inclusion of liquid steel adopting $CaO-Al_2O_3-MgO$ slag than that in the liquid steel adopting $CaO-SiO_2-Al_2O_3$ slag. After LF refining, CaO and CaS content in inclusions increase and is sphere shaped. The CaO/Al_2O_3 rate of the calcium aluminate inclusions adopting $CaO-Al_2O_3-MgO$ slag gradually is close to 1, which is located at the low-melting-point region of the $CaO-Al_2O_3$ phase

diagram[3], while the CaO content of the calcium aluminate inclusions adopting $CaO-SiO_2-Al_2O_3$ slag is around 30%.

By $CaO-Al_2O_3-MgO$ slag, the inclusions in the liquid steel at early stage of LF refining composes of Al_2O_3 inclusions which will be transformed into $CaO-MgO-Al_2O_3$ inclusions by LF refining. At the end of LF refining process, most of inclusions have been transformed into tiny globular $CaO-MgO-Al_2O_3-CaS$ 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 $CaO-Al_2O_3-MgO$ slag is obviously higher than that in the liquid steel adopting $CaO-SiO_2-Al_2O_3$ slag.

2)CaO and CaS occupy a bigger proportion in the inclusion of liquid steel adopting $CaO-Al_2O_3-MgO$ slag than that in the liquid steel adopting $CaO-SiO_2-Al_2O_3$ slag.

3)At the end of LF refining process, most of non-metallic inclusions have been transformed into tiny globular $CaO-MgO-Al_2O_3-CaS$ composite inclusions which are helpful for the improvement of the quality of gear steel.

References

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