Effect of Magnesium Addition on the Inclusions Composition in the Cast Microstructure of HSLA Steel

Yan LIU[1, a,*], Kai WANG[2, b], Yang LIU[2, c], Jian-Ming WANG[2, d]

[1]The Liaoning Provincial Key Laboratory of Advanced Materials & Preparation Technology, Shenyang University, Shenyang, 110044, China

[2]School of Mechanical Engineering, Shenyang University, Shenyang 110044, China

[a]liuyanneu@163.com, [b]wkai1991@foxmail.com, [c]shendacaijialy@126.com, [d]wjmlucky1979@163.com

*Corresponding author

Keywords: Magnesium, Cast Microstructure, Inclusions Composition, HSLA Steel.

Abstract. The rapid development of the large steel structure brings a great opportunity for steelmaking industry. The steel plates not only have the strength and toughness but also can withstand the high energy input welding. Using the magnesium oxide of high melting-point and high stability to pin the grain boundaries is an effective method to improve the welding performance of the structure steel. The effect of magnesium addition on the morphology and composition of the inclusions in the cast microstructure of HSLA steel was analyzed. The results show that the distribution of the inclusions is more dense and uniform with respect to the raw steel, and the size of the inclusions is smaller than the ones in the raw steel after adding magnesium elements. Adding magnesium element in different amounts can lead to the large difference in the composition of the inclusions. The main components of the inclusions formed are magnesium oxides and the composite inclusions, as well as the oxides, sulfides and composite inclusions of the other metallic elements. And most magnesium inclusions are spherical and ellipsoidal.

Introduction

The rapid development of the large steel structure brings a great opportunity for steelmaking industry. However, as the design requirements improve and the manufacturing technology of the steel structure advances, the requirements for the performance of steel plates which are used to fabricate the steel structure also improve continuously [1]. The steel plates not only have the strength and toughness but also can withstand the high energy input welding [2,3]. Using the magnesium oxide of high melting-point and high stability to pin the grain boundaries is an effective method to improve the welding performance of the structure steel. If this method combines with TMCP (Thermo Mechanical Control Process), we can get the high heat input welding high-strength low alloy (HSLA) steel, which has good toughness and weldability.

The experiment takes a kind of HSLA steel as the research object and analyses the effect of magnesium addition on the morphology and composition of the inclusions in the cast microstructure. The study can provide a reliable theoretical basis and technical support for the development and application of high heat input welding HSLA steel which has good strength and toughness. The research results can transform into productivity and create a new growth point for the national economy.

Experiments

Experimental Materials

A kind of HSLA steel is designed in this experiment. The components of the steel are obtained by smelting pure iron and adding the corresponding alloy. The components of pure iron and main alloy are shown in Tab.1. Magnesium is added in the form of Mg-Zr alloy. Other alloys include electrolytic manganese (99.9%), ferrovanadium (78.6%), ferrotitanium (99%), ferroniobium

(65.6%), ferronickel (78.6%), ferrochromium (85.5%) and molybdenum (76.3%).

Tab.1 Components of pure iron and main alloys (wt%)

Alloy	C	Si	Mn	P	S	Al	Fe	Ca	Mg	Zr	Ni	Cu
Pure iron	0.0013	0.01	0.05	0.007	0.0044	0.0013	92.6	/	/	/	/	/
Fe-Si	0.024	78.96	0.058	0.0093	0.0037	0.24	20.24	/	/	/	/	0.049
Mg-Zr	/	0.0053	0.0061	/	/	0.0053	0.029	/	69.68	30.12	0.15	0.0014

Smelting Equipment and Process

The solid solution, segregation and precipitation produced by microalloy in steel lead to the grain refinement, precipitation strength, recrystallization control and the deformation of inclusions, which play a major role to improve the performance of the steel [4]. The effect of micro-alloying elements on the HSLA steel is shown in Tab.2 [5]. Ca and Mg metallic elements are added to form high smelting-point oxides, improving toughness and weldability of the steel plate.

Tab.2 Effect of micro-alloying elements on the HSLA steel

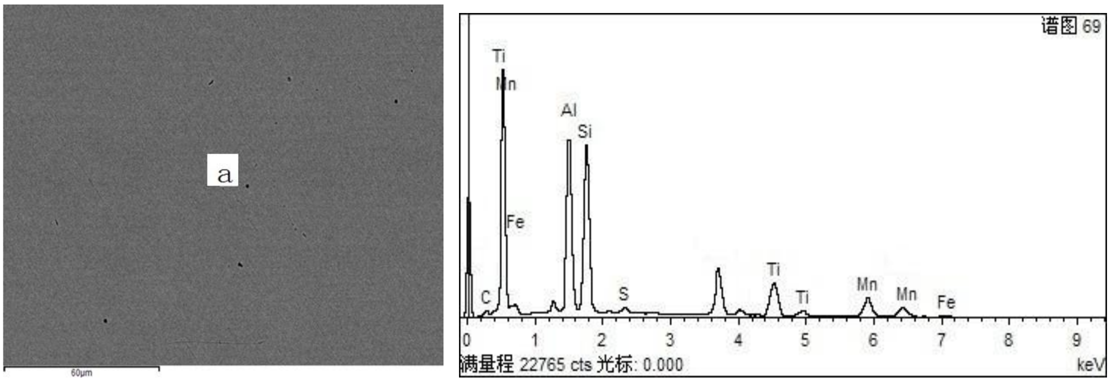
Item		Microalloyed elements		
		Nb	V	Ti
Strengthing and toughening effect	Grain refinement	Significant effect	Effective	Effective
	Precipitation strength	Effective	Significant effect	Not obvious
	Nitrogen fixation effect	Not obvious	Effective	Significant effect
	Maneuverability of controlled rolling	Significant effect	Significant effect	Not obvious
	Maneuverability of controlled cooling	Effective	Significant effect	Not obvious
Common problems	Difficulty to control strength	Not obvious	Effective	Not obvious
	Difficulty of micro alloy	Not obvious	Not obvious	Effective
	Pouring difficulty	Not obvious	Not obvious	Effective
	Casting blank crack	Effective	Not obvious	Not obvious
Comprehensive performances		Significant effect	Effective	Effective

We designed a kind of HSLA steel. The experimental steel was smelted in BJ-VIM-5 vacuum induction melting furnace. The four furnaces in the test were accomplished in the order of no magnesium addition, 1 wt% Mg addition, 3 wt% Mg addition and 5 wt% Mg addition.

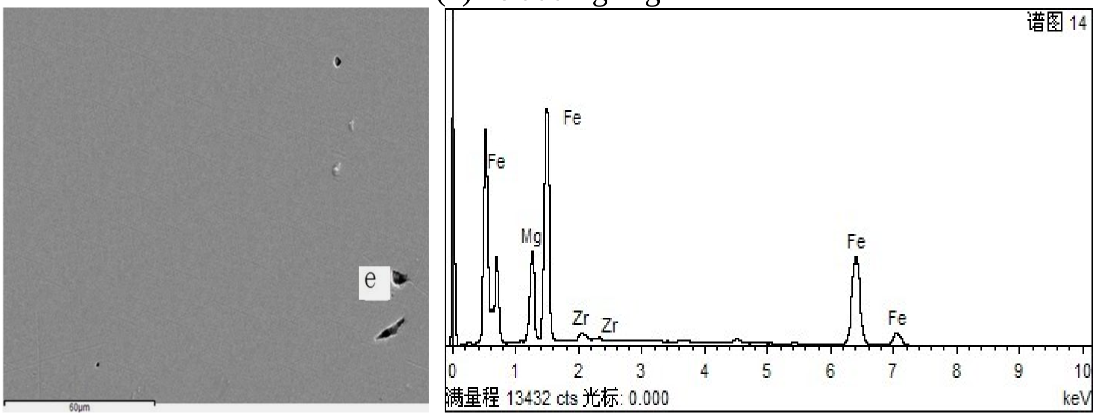
The steps of smelting the experimental steel are as follows. (1) The raw materials are put into the crucible. We must adopt the principle of tightness below and looseness above in order to make the smelting process go smoothly, when we add the raw materials. (2) After adding the raw materials, we begin to vacuumize. When the vacuum degree reaches 1.0×10^{-2} Pa, we begin to heat. (3) We turn up the power gradually in the heating process until the raw materials melt totally. (4) The argon gas as protective gas is filled in the whole smelting process to prevent the raw materials from oxidating. When the steel boils, we add alloy by a special method. (5) After adding alloy, we begin to stir it. After refinement for several minutes, we turn off the heating equipment and begin to pour. (6) After cooling for three hours, the casting mould is taken out.

Effect of Magnesium Addition on the Inclusions Composition in the Cast Microstructure of the HSLA Steel

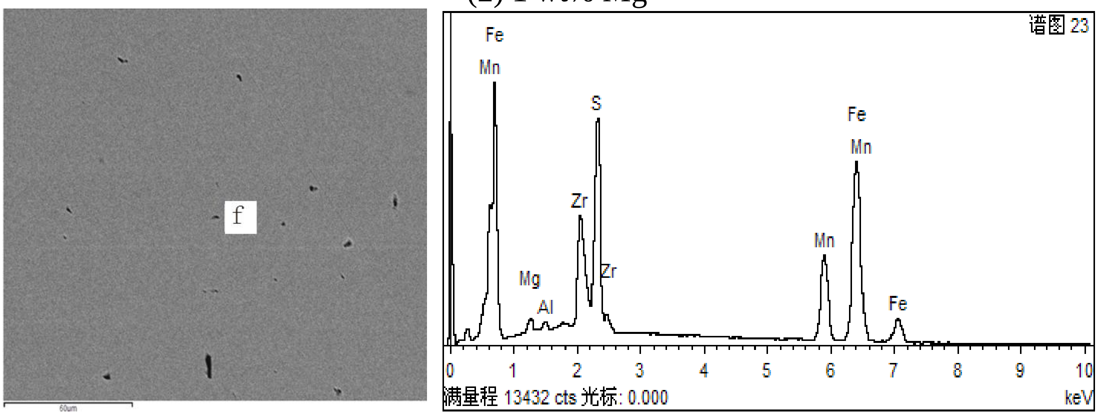
The Morphology and Composition of the Inclusions in the Cast Microstructure



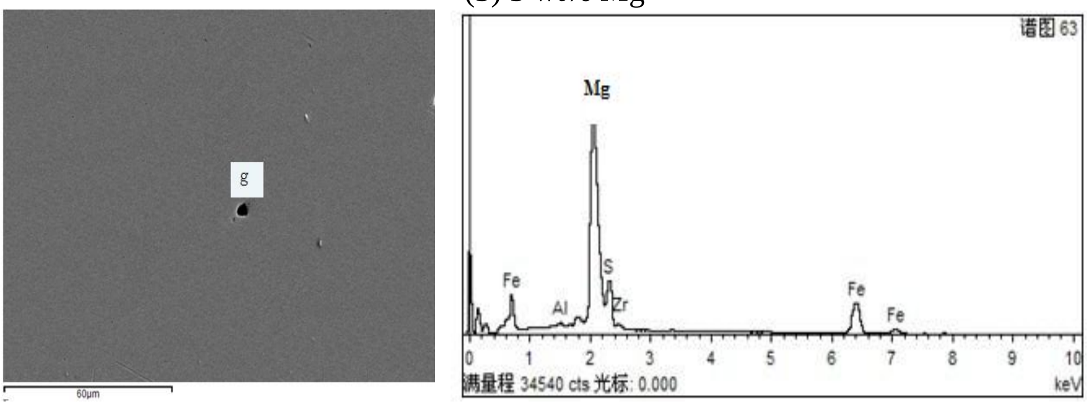
(1) no adding Mg



(2) 1 wt% Mg



(3) 3 wt% Mg



(4) 5 wt% Mg

Fig.1 The morphology and composition of the inclusions in each sample

The scanning electron microscope (SEM) and energy dispersive spectrometer (EDS) were used to analyze the morphology and composition of the inclusions in the cast microstructure of the HSLA steel. The results of the 1-4# experimental steel are respectively shown in Fig. 1.

Results Analysis

From SEM and EDX analysis results, adding Mg element in different amounts can lead to the large differences in the type, quantity, composition and distribution of the inclusions. The specific analysis is shown in Fig.1.

Through the contrast analysis to the morphology of the inclusions in the samples, we can find that after adding Mg element, the distribution of the inclusions is more dense and uniform with respect to the raw steel, and the size of the inclusions is smaller than the ones in the raw steel.

Fig.1 (1) is the figure of the electron backscatter diffraction (EBSD) and EDS in the raw steel, the inclusions are mainly the TiO_X-Al_2O_3-SiO_2-MnS composite ones. Fig.1 (2) is the figure of the electron backscatter diffraction (EBSD) and EDS in 1 wt% Mg steel, the inclusions are mainly ZrO_2-MgO. Fig.1 (3) is the figure of the EBSD and EDS in 3 wt% Mg steel, the inclusions are mainly ZrO_2-MnS-MgO-Al_2O_3. Fig.1 (4) is the figure of the EBSD and EDS in 5 wt% Mg steel, the inclusions are mainly MgO-ZrO_2-Al_2O_3.

In a word, the study found that lots of Mg oxides and inclusions formed after pouring into ingots owing to the adding Mg element. The distribution of the inclusions is homogeneous, the size of the inclusions is even small, and most Mg inclusions are spherical and ellipsoidal. Adding Mg element in different amounts can lead to the large difference in the composition of the inclusions.

Conclusions

Magnesium elements were added into molten steel in the form of Mg-Zr alloy in the experiment. The experiment takes a kind of HSLA steel as the research object and analyses the effect of magnesium addition on the morphology and composition of the inclusions in the cast microstructure of the HSLA steel by using SEM and EDX analysis.

(1) Adding Mg element in different amounts can lead to the large differences in the type, quantity, composition and distribution of the inclusions.

(2) Through the contrast analysis to the morphology of the inclusions in the samples, we can find that after adding Mg element, the distribution of the inclusions is more dense and uniform with respect to the raw steel, and the size of the inclusions is smaller than the ones in the raw steel.

(3) Lots of Mg oxides and inclusions formed after pouring into ingots owing to the adding Mg element. And most magnesium inclusions are spherical and ellipsoidal. The main components of the inclusions formed are magnesium oxides and the composite inclusions, as well as the oxides, sulfides and composite inclusions of the other metallic elements.

Acknowledgments

This work was supported by the Liaoning Province Natural Science Fund Project (No. 2014020097), the Project for Liaoning Provincial Scientific Research in University of China (No. L2014475) and the Open Subject Fund of the State Key Laboratory of Rolling and Automation of NEU, China (No. 2009003).

References

[1]Y. Gan, H. Dong, Recent progress in advanced steel technologies, China Metallurgy. 8 (2004) 1-6.

[2]Z.D. Huang, Q.K. Cai, J.P. Niu, Research progress of iron and steel material strengthened by particle, Hot Working Technology. 40 (2011) 79-83.

[3]T. Senuma, Present status and future prospects for precipitation research in the steel industry,

ISIJ Int. 42 (2002) 1-12.

[4]L.Q. Zhang, Research on high heat input welding alkaline metals micro-alloyed high strength low-alloyed steels, Wuhan University of Science and Technology. (2009).

[5]Y.T. Chen, A.M. Guo, P.H. Li, Nitride and carbonitride precipitation behavior in a Nb-Ti microalloyed extra low carbon HSLA steel, Heat Treatment of Metals. 32 (2007) 51-54.