The influence of high heat input and inclusions control for rare earth on welding in low alloy high strength steel

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Abstract. In the current paper, it is analyzed for the influence of high heat input and inclusions control for rare earth on welding in low alloy high strength steel. It is observed for the structure for different heat input of the coarse-grained area. It is finest for the coarse grain with the high heat input of 200 kJ / cm and the coarse grain area with 400 kJ / cm is the largest. The performance with the heat input of 200 kJ / cm for -20 ℃ V-shaped notch oscillatory power is better than the heat input of 400 kJ / cm. The grain structure is the ferrite and bainite for different holding time. The grain structure for 5s holding time has a grain size of 82.9 μm with heat input of 200 kJ/cm and grain size of 97.9 μm for 10s holding time. For the inclusions for HSLA steel with adding rare earth, they are Al_2O_3-CaS inclusions in the Al_2O_3-CaS-CaO ternary phase diagram. At the same time, it can not be found for low melting calcium aluminate inclusions compared to the inclusions for the HSLA steel without rare earth. Most of the size for the inclusions is between 1 ~ 10μm. The overall grain structure is smaller and the welding performance is more excellent for adding rare earth.

1. Introduction

At present, high heat input welding has become a trend. But the high heat input welding makes toughness and strength reduced for the weld joint. The Rare Earth (Re) can refine the grain to improve strength and toughness and also can change the shape and distribution of the inclusions in steel. There are also some studies on the effect of Re in high heat input for welding and the induction of acicular ferrite behaviour for laboratory studies[1~5]. But there is little research for the base metal especially the control for the Re to improve the toughness in the industrial production in low alloy high strength (HSLA) steel. Re elements play an important role in the refinement of grains and the formation of intragranular ferrite. Also it can enhance the impact toughness at low temperature and welding performance for HSLA steel for refinement of heat affected zone grain size for high heat input welding. Therefore, it is important for the influence of inclusions for rare earth on welding in HSLA steel.

2. Experiment Procedure

2.1 Steelmaking process for HSLA steel

In this paper, testing and analysis in steelmaking process were tracked and done in some manufacturers for HSLA steel plate production. The steelmaking process for HSLA steel is Pretreatment of hot metal → LD → LF refining → RH refining → Calcium treatment → CC as shown in Fig. 1. The Re content in alloy is more than 95% which the ratio of cerium and lanthanum is 2 for HSLA steel.
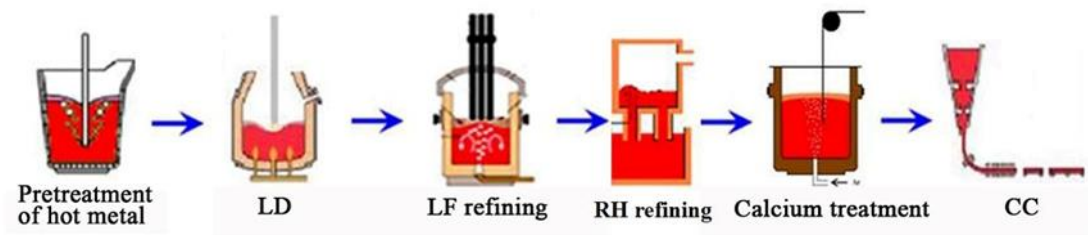
Fig. 1 Steelmaking process for HSLA steel

3. Results and Discussion

3.1 The thermal simulation test for high heat input
The structure and properties of 200kJ / cm heat input for welded coarse grain regions were simulated by Gleeble 2000D thermal simulation test machine. The peak heating temperature is 1350 ℃ and the holding time is 3S. The corresponding welding characteristic parameter $t_{8/5}$ is 120s, and the thermal cycling curve is shown in Fig. 2.
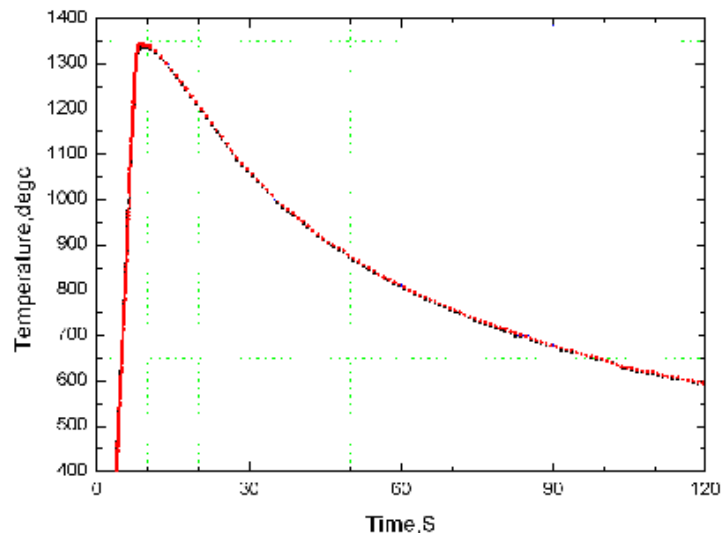

Fig. 2 Peak temperature 1350 ℃ for 200KJ / cm welding thermal cycle curve

3.2 The structure for different high heat input
It is observed for the structure for different heat input of the coarse-grained area. We can draw a conclusion from Fig. 3 that it is finest for the coarse grain with the high heat input of 200 kJ / cm and the coarse grain area with 400 kJ / cm is the largest. The performance with the heat input of 200 kJ / cm for -20 ℃ V-shaped notch oscillatory power is better than the heat input of 400 kJ / cm.
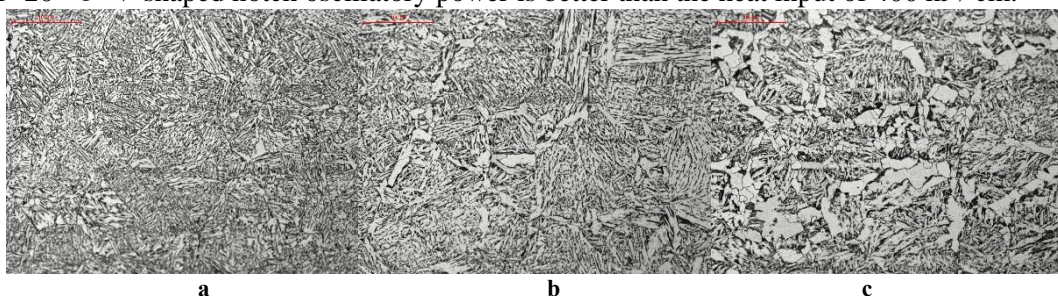

a   b   c
Fig. 3 Grain structure for different heat input welding (a: 200 kJ/cm; b: 300 kJ/cm; c: 400 kJ/cm)

3.3 The structure for different holding time

It is analyzed for the structure for different holding time of the coarse-grained area. We can see from Fig. 4 that it is finest for the coarse grain for 5s holding time with the high heat input of 200 kJ / cm and the coarse grain area with 10s holding time is the largest. From Fig. 4 we can also see that the grain structure is the ferrite and bainite. The grain structure for 5s holding time has a grain size of 82.9 μm with heat input of 200 kJ/cm and grain size of 97.9 μm for 10s holding time.
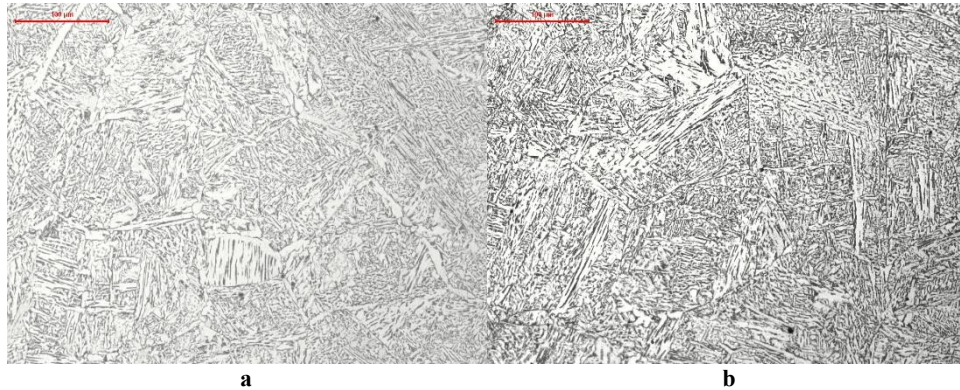

Fig. 4 Grain structure for different holding time with heat input of 200 J/cm (a: 5s for holding time; b: 10s for holding time)

3.4 The control of inclusions
Re plays a role on the inclusions for a certain degree of denaturation for the inclusions spheroidization to improve the strength of steel. The study was carried out by means of ASPEX to automatically scan the sample inclusions by the effect of the addition of Re on the denaturation behavior of the inclusions. The control of inclusions has become a key to the HSLA steel with Re. Size and morphology of the inclusions for the HSLA steel with Re in some factory are shown in Fig. 5. For the inclusions for HSLA steel with adding Re, they are Al_2O_3-CaS inclusions in the Al_2O_3-CaS-CaO ternary phase diagram. At the same time, it can not be found for low melting calcium aluminate inclusions compared to the inclusions for the HSLA steel without Re. Most of the size for the inclusions is between 1 ~ 10μm. We can see from Fig. 6 ~ Fig. 8 that the inclusions contain La and Ce for Res and they really play an important effect on the control of inclusions and the performance of plates.
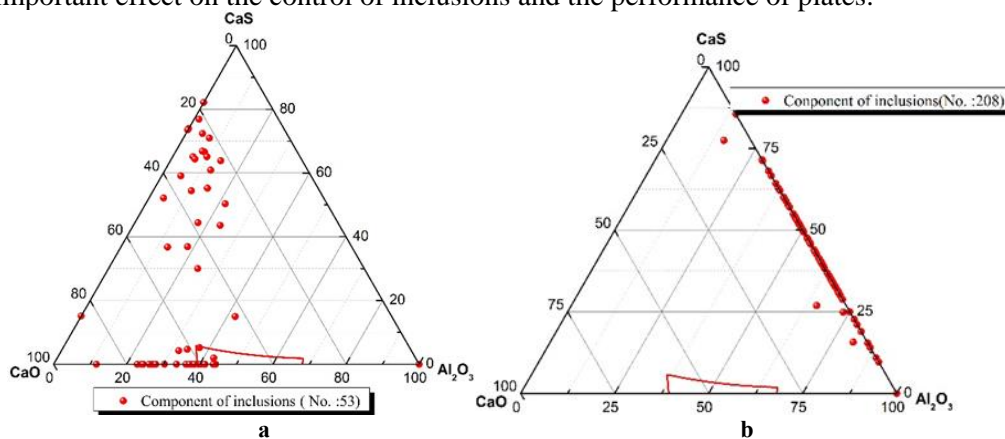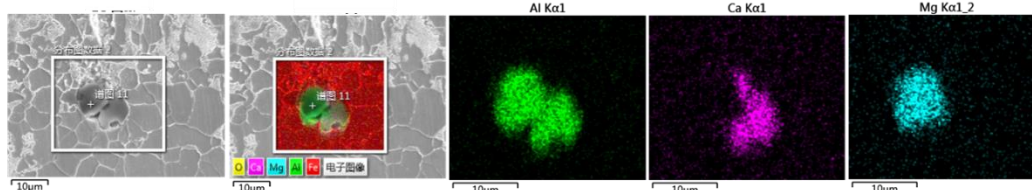

Fig. 5 Component distribution of inclusions for the HSLA steel (a: inclusions with Re; b: without Re)
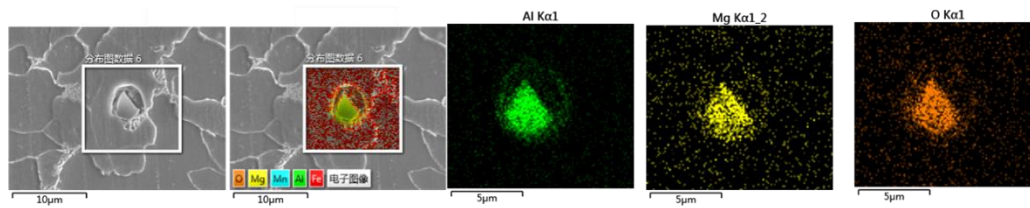
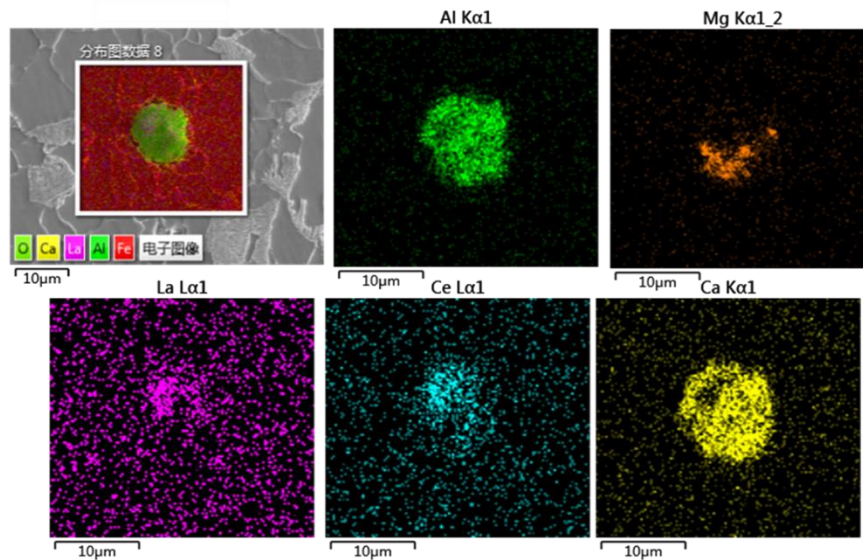**Fig. 6** Inclusion surface scan results for HSLA steel without Re

Fig. 7 Inclusion surface scan results for HSLA steel with Re
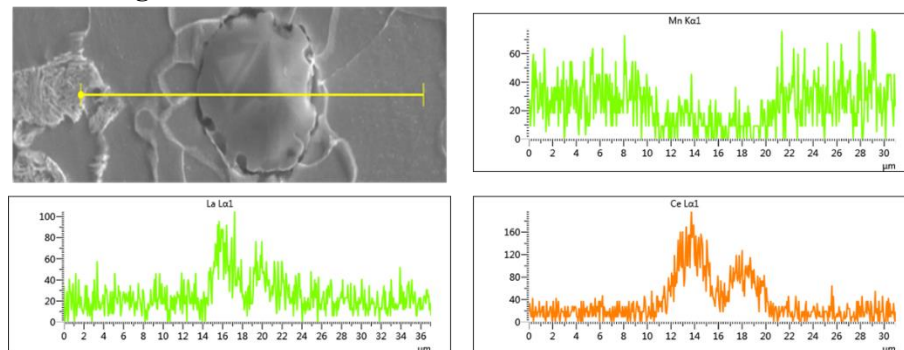

Fig. 8 Inclusion line scan results for HSLA steel with Re

3.5 The grain structure for plate adding Re and without Re
It is observed for the structure of the welded joint with 200 kJ / cm heat input in the coarse-grained area. We can draw a conclusion from Fig. 9 that it is finer for the coarse grain with the high heat input of 200 kJ / cm for adding Re. It is a small amount of acicular ferrite and a large number of massive ferrite for the grain structure for plate without Re of the weld metal. We can also draw a conclusion that the deposited metal structure contains a large amount of acicular ferrite. The overall grain structure is smaller and the welding performance is more excellent.
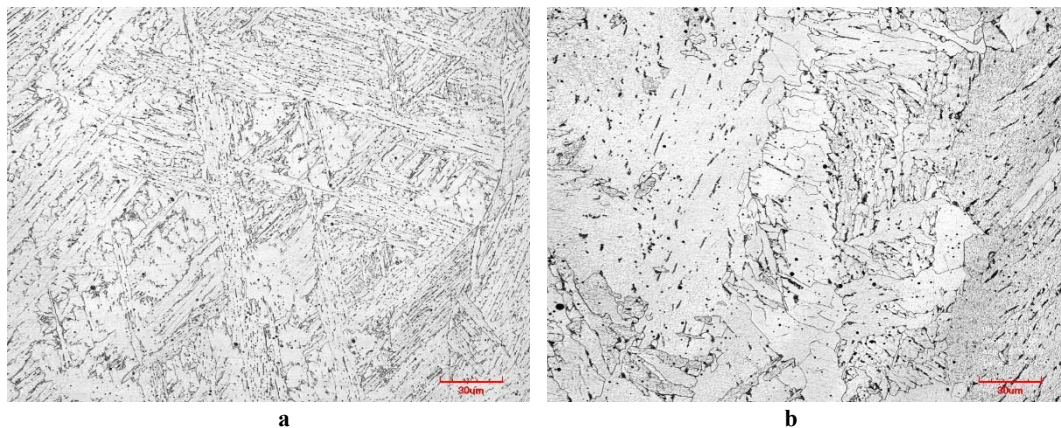
a   **b**

Fig. 9 The grain structure for plate adding Re and without Re(a: inclusions with Re; b: without Re)

4. Conclusions

(1) It is observed for the structure for different heat input of the coarse-grained area. It is finest for the coarse grain with the high heat input of 200 kJ / cm and the coarse grain area with 400 kJ / cm is the largest. The performance with the heat input of 200 kJ / cm for -20 ℃ V-shaped notch oscillatory power is better than the heat input of 400 kJ / cm.

(2) The grain structure is the ferrite and bainite for different holding time. The grain structure for 5s holding time has a grain size of 82.9 μm with heat input of 200 kJ/cm and grain size of 97.9 μm for 10s holding time.

(3) For the inclusions for HSLA steel with adding Re, they are Al_2O_3-CaS inclusions in the Al_2O_3-CaS-CaO ternary phase diagram. At the same time, it can not be found for low melting calcium aluminate inclusions compared to the inclusions for the HSLA steel without Re. Most of the size for the inclusions is between 1 ~ 10μm

(4) The overall grain structure is smaller and the welding performance is more excellent for adding Re.

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