

Effect of Calcium Addition on the Rolled Microstructure of a Kind of HSLA Steel

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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 calcium 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. Calcium was added into molten steel in the form of Ca-Si alloy using the special process in the experiment. A kind of HSLA steel containing Ca was prepared by means of the vacuum induction melting and controlled rolling and controlled cooling experiments. The effect of calcium addition on the rolled microstructure of HSLA steel was analysed. The results show that the addition of Ca elements has a significant effect on the microstructure of the rolled steel. The rolled microstructure of the experimental steel consists of polygonal ferrite and granular bainite and small amount of pearlite. The emergence of bainite is favorable to the strength and toughness of the experimental steel.

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 [1-3]. The steel plates not only have the strength and toughness but also can withstand the high energy input welding [4-6]. Using the calcium 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.

Calcium was added into molten steel in the form of Ca-Si alloy using the special process in the experiment. A kind of HSLA steel containing Ca was prepared by means of the vacuum induction melting experiments and controlled rolling and controlled cooling experiments, and the effect of calcium addition on the rolled microstructure of the HSLA steel was analysed. The study can provide a reliable theoretical basis and technical support for the development and application of high heat input welding HSLA steel. The study can reduce production costs and save social resources effectively. 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 was designed in this experiment. The components of the steel were obtained by smelting pure iron and adding the corresponding alloy. The components of pure iron and main alloy were shown in Table 1.

Calcium was added in the form of Ca-Si alloy. Other alloys included electrolytic manganese (99.9%), ferrovanadium (78.6%), ferrotitanium (99%), ferroniobium (65.6%), ferronickel (78.6%), ferrochromium (85.5%) and molybdenum (76.3%).

Table 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
Si-Ca	0.13	66	/	2.6	/	0.15	/	31	/	/	/	12

We designed a kind of HSLA steel, based on the above principle and absorbing predecessors's research experiences. The BJ-VIM-5 vacuum induction melting furnace was used in the smelting experiment of HSLA steel. The MgO crucible was used in the test. The four furnaces in the test were accomplished in the order of no calcium addition, 1 wt% Ca addition, 3 wt% Ca addition and 5 wt% Ca addition.

Process of Rolling and Cooling. The experiment of rolling and cooling used the $\Phi 450$ hot rolling machine group and controlling cooling system. The start rolling temperature was 1200°C. The fourth pass rolling temperature was controlled at about 950°C \sim Ar₃, and the final rolling temperature was controlled at 950 \sim 700°C. After rolling, the temperature was reduced to 380°C by water cooling, then air cooling [7]. The rolling temperature of the pass steel plate was measured by the infrared thermometer, and the cooling time was determined by the stopwatch, so the cooling rate could be calculated. The rolling process parameters of the experimental steel were shown in Table 2, and the cooling process parameters were shown in Table 3.

Table 2 Rolling process parameters of experimental steel

Experimental steel	Start rolling temperature (°C)	Final rolling temperature (°C)	Thickness after rolling (mm)
Ca1%	1200	810	12.1
Ca3%	1190	790	12
Ca5%	1230	850	12.2
The original steel	1950	770	11.9

Table 3 Cooling process parameters of experimental steel

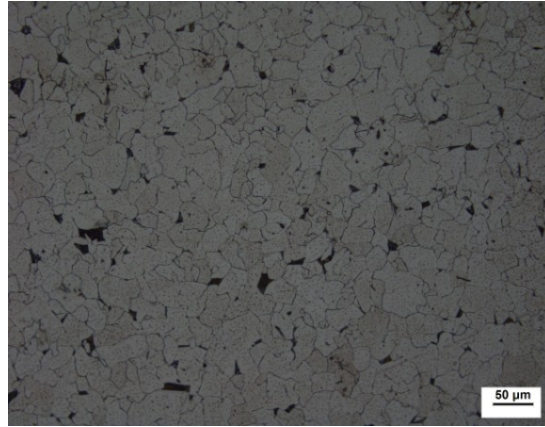
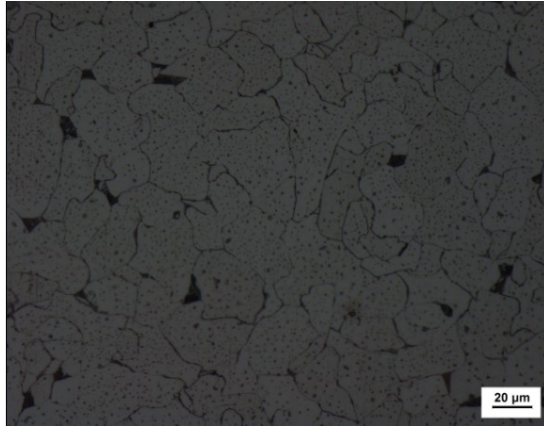
Experimental steel	Start cooling temperature (°C)	Final cooling temperature (°C)	Cooling rate (°C·s ⁻¹)
Ca1%	800	375	19.6
Ca3%	780	355	23.1
Ca5%	830	190	25.6
The original steel	750	380	35.3

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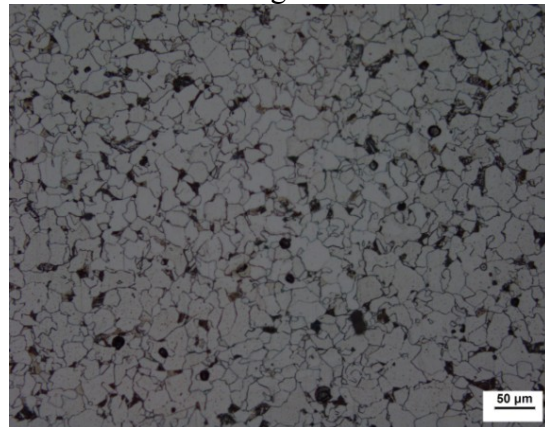
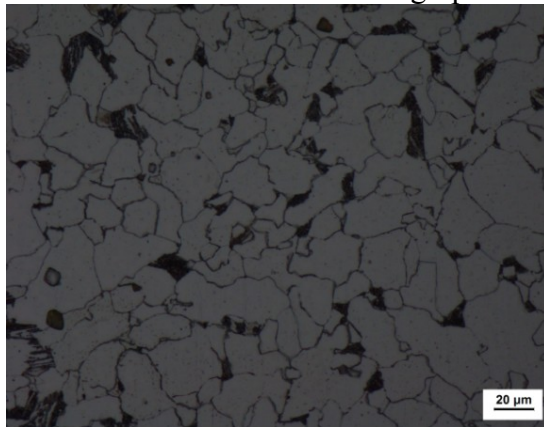
The prepared metallographic samples zoomed in 200 and 500 times were respectively observed using the OLYMPUS-CK40M optical metallographic microscope. The diagrams of rolled microstructure of the HSLA steel were obtained.

The contrast diagrams of the rolled microstructure at the bottom of the samples of the HSLA steel were shown in Fig. 1 (a-d), including no calcium addition (the original steel), 1 wt% Ca addition, 3 wt% Ca addition and 5 wt% Ca addition.

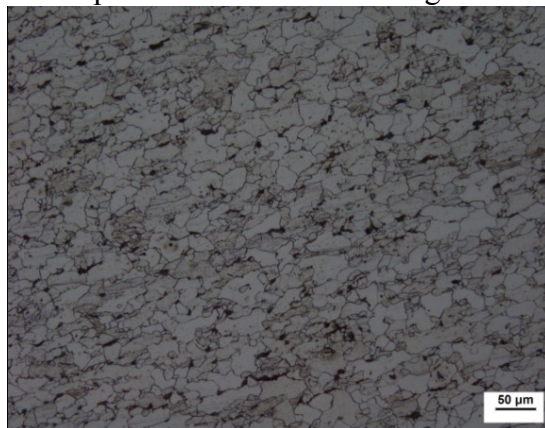
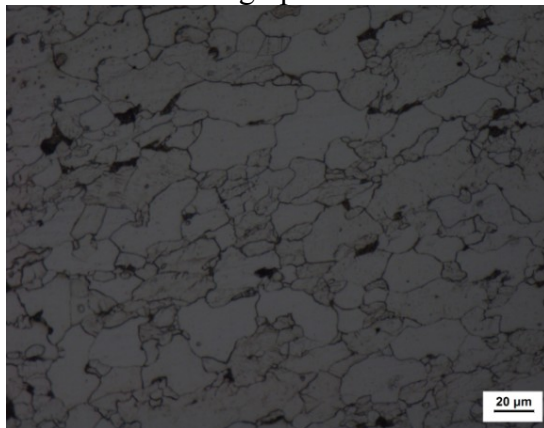
The microstructures that often can be found in the common steel are bainite, martensite, pearlite, ferrite, and so on. We can find that there are some differences in the microstructure among each experimental steel. The observation results of rolled microstructure were tabulated and shown in Table 4.



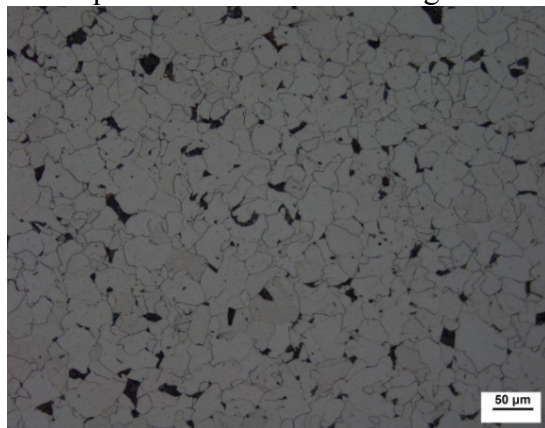
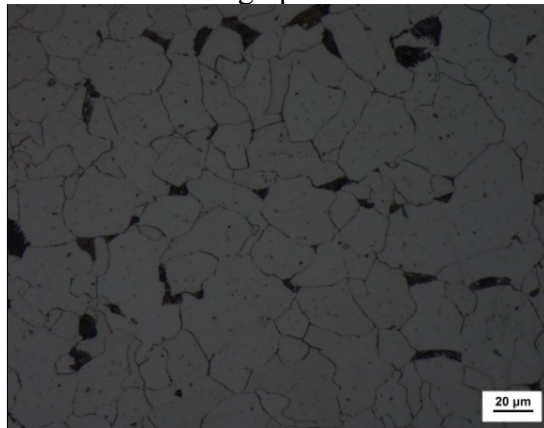
a. the rolled metallographic microstructure of the original steel



b. the rolled metallographic microstructure of the experimental steel containing 1 wt% Ca



c. the rolled metallographic microstructure of the experimental steel containing 3 wt% Ca



d. the rolled metallographic microstructure of the experimental steel containing 5 wt% Ca

Fig. 1 Rolled microstructure comparison diagrams of each sample containing Ca

Table 4 Microstructure observation results of rolled steel containing Ca

Experimental steel	The observation results of microstructure
The original steel	polygonal ferrite + small amount of quasi-polygonal ferrite + small amount of pearlite
Ca1%	polygonal ferrite + quasi-polygonal ferrite + small amount of pearlite + small amount of bainite
Ca3%	polygonal ferrite + moderate quasi-polygonal ferrite + small amount of pearlite + extremely small amount of bainite
Ca5%	polygonal ferrite + quasi-polygonal ferrite + small amount of pearlite

From the above analysis results, it can be seen that the samples are rolled after melting and austenitizing, and the cast microstructure has been changed after rolling and the deformed austenite. The rolled microstructure of the experimental steel consists of polygonal ferrite and granular bainite and small amount of pearlite. For the experimental steel of different compositions and contents, the proportion of bainite and ferrite has a certain gap, which will lead to some differences in mechanical properties.

Conclusions

Calcium was added into molten steel in the form of Ca-Si alloy using the special process in the experiment. A kind of HSLA steel containing Ca was prepared by means of the vacuum induction melting experiments and controlled rolling and controlled cooling experiments, and the effect of calcium addition on the rolled microstructure of the HSLA steel was analysed.

(1) The samples are rolled after melting and austenitizing, and the cast microstructure has been changed after rolling and the deformed austenite.

(2) The addition of Ca elements has a significant effect on the microstructure of the rolled steel. The rolled microstructure of the experimental steel consists of polygonal ferrite and granular bainite and small amount of pearlite. The emergence of bainite is favorable to the strength and toughness of the experimental steel.

(3) For the experimental steel of different compositions and contents, the proportion of bainite and ferrite has a certain gap, which will lead to some differences in mechanical properties.

Acknowledgments

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