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Aluminum Control in CrNiMoV Steel during Electroslag Remelting Process

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Abstract: The residual aluminum content has a great influence upon CrNiMoV steel properties and the optimal content is about 0.010%. The aluminum control during the ESR process has been investigated in this paper. All experiments were carried out in a 20 kg ESR furnace. The results show that when a 60%CaF_2 − 30%Al_2O_3 − 5%SiO_2 − 5%CaO slag system and proper deoxidizing schedule is used, a reasonable ingot with optimal aluminum contents can be obtained. Silicon and magnesium contents are approximately the same with those in the electrode.
Key words: ESR, aluminum, CrNiMoV steel

As a high-quality steel, CrNiMoV grade has an excellent through quench property. It is possible to get a good combination of strength and toughness after quench-temper treatment. However, a great improvement in quality depends, to a large extent, upon the melting technique used. Besides alloy element adjustment, to control the amount of inclusions and minor elements, especially the residual aluminum, is very important for improving the properties of steel. Different aluminum contents result in different sizes and quantities of oxide, nitride and sulfide inclusions during freezing and hot rolling processes, which affect mechanical propertie So far, many developed countries successively made standards that the residual aluminum in steel must be below 0.015%. In France, the average of several practical heats was 0.009%. Their controlling technique is protected as a secret[1].

The previous work on CrNiMoV steel indicate that too high or too low contents of aluminum would reduce the complex mechanical property of steel and the optimum content is about 0.01%[2].

It is well known aluminum is an active element and very difficult to accurately control during the ESR process. At present, the residual aluminum content in CrNiMoV steel ingot varies within a large range in practice. Even if in the same ESR ingot, it is higher in the bottom section and lower in the top section, which makes its mechanical properties inconsistent along ingot axis. Therefore, how to control the residual aluminum content under industry conditions is a probmle to be solved.

1 Experimental

In practice, 65%CaF_2 -35%Al_2O_3 slag systems are widely used for electroslag remelting, which are familiar to the workers and technologists. Therefore, the experiments on controlling residual aluminum contents in steel were carried out with a CaF_2 − Al_2O_3 − SiO_2 − CaO slag system based on 65%CaF_2 − 35% Al_2O_3. The experiment schedule is as follows: forging returned steel into electrodes of 80 mm in diameter, grinding electrodes to remove oxidized surface, remelting in a 20 kg ESR furnace.

The different kinds of oxidants were added to the furnace in an interval of five seconds. The raw slag materials are the industry fluorite (CaF_2 ≥ 98%) and industry alumina (Al_2O_3 ≥ 99%), while SiO_2 and CaO agents are of chemical pure. All heats are started with liquid slag of about 2.0 kg in mass. The electric voltage and current are of 42 V and 2 000 A, respectively.

2 Results and Analysis

The remelting stability and ingot surface quality are depended on process electrical voltage and current slag constitutes. The results show that the surface quality of ESR ingot improves significantly and the process is relatively stable if SiO_2 content is within 5%~10%. More SiO_2 in slag results in violent oxidizing reactions due to its higher oxidizing ability, which makes the remelting current unstable.

Generally, there are three resources that make ingot aluminum content rising, which are aluminum contained in electrode, aluminum reduced from alumina and aluminum added as deoxidant during remelting process respectively. Table 1 presents initial and finished slag constitutes and the amount of residual aluminum in steel.

It is obvious from these data given in table 1 that, accompanying the increase of SiO_2 containing in 65/35 based slag, aluminum contents in the bottom of ESR ingots decrease significantly and appear much higher than those in the top. By adding 5% or 10% SiO_2 to the $CaF_2 - Al_2O_3 - SiO_2$ slag system, there are similar aluminum contents along the ESR ingot, which are of 0.0050%~0.0060% and close to those of electrode, seeing data from No. 3 to 7 in table 1. This indicates that no aluminum but SiCa or SiBa additions for deoxidization could not adjust the aluminum level from 0.005% to 0.010%, since an air atmosphere exists above the slag pool. In the other hand, SiCa or SiBa deoxidizing have little effect on controlling residual aluminum since they are all in powder and burned violently on the surface of the slag. Nevertheless, it is clear from heat No. 9 and 10, much higher aluminum contents, up to 0.018%, exist in steel when aluminum is added under 65/35 slag operation. Also, the residual aluminum content is much higher in the bottom than in the top, which result from higher Al_2O_3 and lower SiO_2 containing in the operating slag in the beginning period. Al_2O_3 is reduced by silicon and manganese. It had been proved that there is a difference of manganese contents between the bottom and the top, seeing table 2.

Based on the above data, another experiment was performed in the laboratory and only aluminum particle was used as deoxidant. Fig. 1 gives the effect of aluminum additions on the residual aluminum in steel. The residual aluminum content rises significantly as the aluminum additions increase.

Aluminum added for deoxidizing alone appears three behaviors during electroslag remelting process: burning above the slag under high temperature, deoxidizing and dissolving into the melt directly.

$$4Al_l + 3O_2 = 2(Al_2O_3)$$
$$4Al_l + 3(SiO_2) = 2(Al_2O_3) + 3[Si]$$
$$4Al_l + 3(FeO) = (Al_2O_3) + 3[Fe]$$
$$Al_l = [Al]$$

Among them, ratio of aluminum consumed in each equation mainly depends on slag constitutes and aluminum additions. The more the amount of aluminum additions, the higher the dissolved aluminum is. As the percentage of FeO in slag keeps a certain level under the same atmosphere and operating conditions, increasing in SiO_2 content in slag would result in decreasing in dissolved aluminum. The follow ing reaction may play an important role

$$3[Si] + 2(Al_2O_3) = 4[Al] + 3(SiO_2)$$
$$\Delta G^{\ominus}=170\,000 - 19.18\,T$$

Table 1 Variation of residual aluminum and slag composition*

No.	Slag system	Terminal SiO_2/ %	Deoxidant	Deoxidant additions/ kg	Residual aluminum(top/bottom)/ %
1	65/35	5.50	–	0	0.005 0/0.012 0
2	65/35	4.55	–	0	0.005 5/0.014 0
3	65/30/5	8.97	SiCa	0.040	0.005 0/0.006 0
4	65/30/5	8.77	SiBa	0.040	0.005 5/0.006 0
5	65/30/5	8.26	SiCa	0.020	0.005 4/0.006 2
6	65/30/5	7.73	SiBa	0.020	0.005 3/0.006 0
7	65/25/10	12.53	SiCa	0.020	0.005 0/0.005 5
8	65/25/10	11.15	Al	0.010	0.013 0/0.017 0
9	65/35	5.32	Al	0.020	0.013 0/0.017 0
10	65/35	4.02	Al	0.030	0.011 0/0.018 0

(* Aluminum contents in electrode are 0.0060%).

Table 2 Ingot compositions after ESR %

Composition	Si	Mn	Cr	V	C
No.9 (top/bottom)	0.27/0.27	0.40/0.39	1.05/1.05	0.15/0.15	0.34/0.33
No.10 (top/bottom)	0.28/0.26	0.42/0.37	1.05/1.05	0.14/0.14	0.36/0.33
Electrode	0.26	0.45	1.07	0.15	0.34

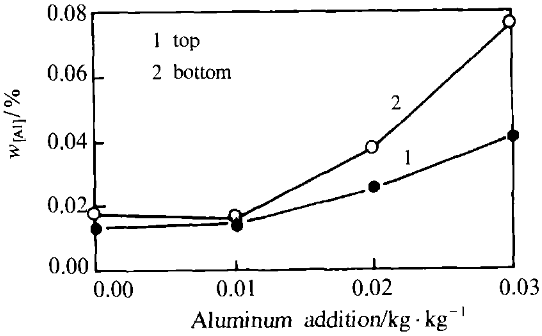

Fig.1 Effect of added Al on the residual Al content in ingot with 65/35 slag

According to the compositions of CrNiMoV steel and activity coefficients[3], the activity of SiO_2 is obtained of 0.635 value. For solute aluminum concentration below 0.02%, its activity may be taken equivalent numerically to concentration in mass fraction. The Gibbs free energy at 1 700℃ is $-242\ 641.3\ J \leq 0$. Increasing SiO_2 content in slag is favorable for controlling aluminum over- rising . In order to prevent silicon and manganese from oxidizing, 5% of CaO is added into the initial slag.

Fig. 2 shows the variation of aluminum in ingots under 5%~6% of SiO_2 slag operation. It is seen that an expected level of aluminum(0.010%) is obtained and an excellent homogeneity exists along the ingot. The optimum aluminum addition is 0.001 2 kg per kilogram of liquid steel.

Adding SiO_2 and aluminum into the slag during the remelting process would not affect other element contents. Silicon, chromium and vanadium keep the same levels as those in electrode, while manganese losses are 0.03%~0.08%. The surface of the remelting ingot is smooth. The processes are much stable and similar to the 65/35 slag operation.

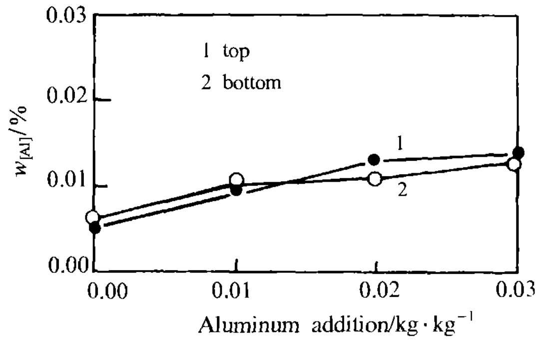

Fig.2 Effect of added Al on the residual Al content in ingot with 60/30/5/5 slag

3 Summary

60%CaF_2-30%Al_2O_3-5%SiO_2-5%CaO slag is beneficial to control optimal aluminum contents in ingots. The proper deoxidant additions are 0.001 2 kg aluminum per kilogram of liquid steel under this slag system operation. There is little variation in other oxygen-sensitive elements' contents.

References

1 Dezhong Bai, Tongwei Huamg. Ordnance Material Science and Engineering, 1987, 66: 75

2 Wenshan Sun, Jie Fu, Aiying Song, et al. J of Univ of Sci and Tech Beijing(in Chinese), 1995, 17(5):412

3 Ying Qu. Principle of Steelmaking(in Chinese). Beijing: Metallurgy Industry Press, 1980.86