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Quantitative Research on Dissolving of Nb in High Nb Microalloyed Steels during Reheating

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Abstract: The accurate prediction of soluble Nb content during reheating is helpful for the design of chemical composition and reheating parameters for Nb-containing steels. The dissolution behavior of Nb in high Nb microalloyed steels was investigated. The results show that Nb does not entirely dissolve for high Nb microalloyed steels containing Ti after holding at 1300 ℃ for 3 h. The soluble Nb content increases with the decrease of C content and/or the increase of Nb content in steels. Moreover, an expression has been established to describe the amount evolution of soluble Nb in high Nb microalloyed steels during reheating and the validity of this expression has also been verified by experiment.

Key words: quantitative research; high Nb microalloyed steel; dissolving; soluble Nb; modeling

Compared with traditional Nb-microalloyed steel (Nb≤0.06%), the Nb content in HTP (high temperature processing) steel is increased significantly to about 0.11%, which makes it become more difficult for dissolving all precipitates of Nb(C,N) during the reheating. Moreover, a small amount of Ti is often added to the high Nb microalloyed steel. Lots of research results[1-5] showed that the Nb(C,N) precipitates cannot dissolve completely during reheating for the Nb steel containing Ti. The existence of lots of undissolved precipitates is not useful for the efficient use of Nb. Therefore, the issue of how much Nb can dissolve during the reheating process needs to be addressed firstly. Due to the lack of the dissolution kinetics data of Nb(C,N) particles in austenite, the soluble Nb content was always considered as the total amount of Nb in steel by soaking at a proper temperature above the solution temperature that was mostly determined by experience and intuition based on solubility product equations[6-8]. Yet because solubility products are too simple for the multicomponent steel, the solution temperature determined by this way is different from the true value[9]. Moreover, solubility products are only appropriate under the equilibrium condition that cannot be satisfied in practical production of steel plates. Therefore, for high Nb microalloyed steel, it is necessary to establish a model for dissolution behavior of precipitates during the reheating process. In this work, the soluble Nb content in six tested steels after different reheating treatments was determined by the inductively coupled plasma-atomic emission spectrometry (ICP-AES), and the relationships among soluble Nb content, heating temperature and the content of C and Nb in steels were also established by the regression analysis, which will be beneficial to the designs of chemical composition and reheating parameters for high Nb microalloyed steels.

1 Material and Methods

The tested steels were prepared in a 25 kg vacuum induction melting furnace, and then the cast slabs

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were hot forged and rolled to the bars of $\phi 12$ mm. The specimens with size of $\phi 10$ mm$\times$8 mm were directly machined from the steel bars. The chemical compositions of tested steels are listed in Table 1. The specimens were heated to different soaking temperatures (950—1300 ℃) and held for 3 h, followed by the water cooling. The powder from specimen was dissolved in hydrochloric acid and the solution was filtrated. The Nb atomic emission spectrometry in solution was measured by inductively coupled plasma-atomic emission spec-trometry (ICP-AES). According to these data, the soluble Nb content in different specimens was obtained[10]. In order to reduce the error, the soluble Nb content in each specimen was measured three times, and then the average was taken.

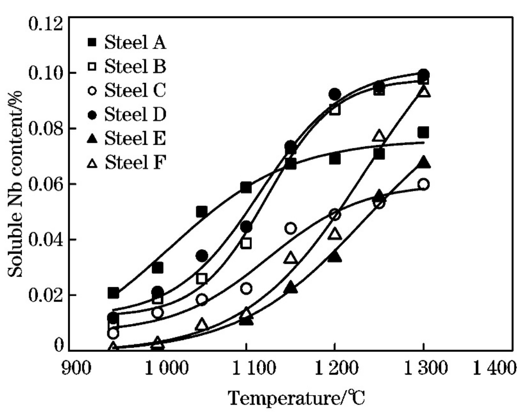
Table 1 Chemical compositions of tested steels

mass%

Steel	C	Si	Mn	Nb	Ti	N
A	0.030	0.25	1.76	0.082	0.017	3.65×10^{-3}
B	0.055	0.26	1.78	0.120	0.011	2.49×10^{-3}
C	0.062	0.27	1.80	0.078	0.021	3.10×10^{-3}
D	0.036	0.24	1.71	0.130	0.011	3.61×10^{-3}
E	0.130	0.29	1.36	0.083	0.016	2.96×10^{-3}
F	0.140	0.29	1.38	0.130	0.021	3.39×10^{-3}

2 Results and Discussion

The soluble Nb content in the specimens held for 3 h at different reheating temperatures was determined. Fig. 1 shows the relationship between soluble Nb content and reheating temperature. The soluble Nb content increases with the temperature increasing. However, the Nb does not entirely dissolve



Points represent experimental data and the curves represent Boltzmann fitting curves.

Fig. 1 Soluble Nb content at different temperatures and the corresponding Boltzmann fitting curves for tested steels

during reheating at 1300 ℃ for 3 h. The increase of soluble Nb content is slow below 1100 ℃, and then rapidly accelerates with further increase of temperature. But, the increase becomes slow again when the soluble Nb content reaches a certain value. Combining Table 1, it can be obtained that when the temperature is low, the soluble Nb content increases with the decrease of C content in steel, while the Nb content has no obvious effect on the soluble Nb content. However, with the increase of the temperature, the effect of Nb content in steel on the soluble Nb content increases gradually, while the effect of C content is becoming less important.

From Fig. 1, it can be seen that the relation between the soluble Nb content and reheating temperature presents an S-type curve, which can be approximately expressed by Boltzmann equation

$$w_{\mathrm{Nbs}}=A_2+(A_1-A_2)/[1+\exp((T-T_0)/\mathrm{d}T)] \quad (1)$$

where, w_{Nbs} is the soluble Nb content, mass%; A_1 and A_2 are the minimum and maximum of soluble Nb content, mass%, respectively; T is the reheating temperature, ℃; T_0 is the temperature at which the soluble Nb content is $(A_1+A_2)/2$; and $\mathrm{d}T$ is the width of the temperature range, in which the soluble Nb content increases drastically with the temperature.

The Boltzmann fitting curves are shown in Fig. 1, and the values of parameters in Eq. (1) determined by regression analysis are listed in Table 2. Combining Table 1, it can be found that there is some relationship between these parameters and the content of C and Nb in steel. However, there are still individual data that are not in accord with the real situation. For example, A_1 of Steel A is negative and A_2 of Steel E is higher than the addition of Nb in steel. Therefore, the parameters need to be revised within the corresponding error range, according to the experimental results shown in Fig. 1. The revised parameters are also listed in Table 2, where $\mathrm{d}T$ takes the average.

By regression analysis, the relationships between the parameters and the content of C and/or Nb are determined, as shown in Fig. 2. It is clear that A_1 and T_0 are linear with $\log w_{\mathrm{C}}$ and A_2 is linear with w_{Nb}, as expressed in following equations:

$$A_1=-(0.017\pm0.001)-(0.020\pm0.001)\log w_{\mathrm{C}} \quad (2)$$

$$A_2=(0.011\pm0.003)+(0.729\pm0.030)w_{\mathrm{Nb}} \quad (3)$$

$$T_0=(1439.2\pm18.2)+(241.2\pm14.9)\log w_{\mathrm{C}} \quad (4)$$

Using Eqs. (1) to (4), the expression for prediction of