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New study concerning development of application of rare earth metals in steels

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Abstract

There are three main roles of rare earth metals played in steels, which are modification of inclusions, deep purifying steel, and alloying. The effect of deep purifying steel means that deep deoxidation, desulfurization, and removing or depressing P, S, As, Sb, Bi, Pb, Sn nocuous actions in steels. The new study results concerning the development of application of rare earth metals in steels have been covered in this paper. The mechanism of corrosion resistance in the RE-weather resistance steel was clarified. The mechanism of abrasion resistance and the life of fatigue enhanced in the RE-heavy rails steel were discussed.

Keywords: Rare earth metals; Micro-alloying elements; Application in steels; RE-weather resistance steel; RE-heavy rails steel

1. Introduction

With the development of metallurgical techniques, the purity of the steels has been improved quite a lot. Since there are some rich resources of RE ores in China, and China is also a biggest steel producer. It is to be significant to carry out the research on the application of RE in the clean steels and to develop RE micro-alloyed steels (such as, RE-weather resistance steel, RE-heavy rails steel and RE-low alloyed steels, etc.) with Chinese characteristics.

2. Experimental

The experimental materials were refined in the vacuum induction furnace. And some samples were taken from the industrial steel plants. The solid solution of RE in the samples were measured by low temperature electrolysis [1] combining inductive coupling plasma (ICP). The chemical compositions of the modified inclusions and the rust layers were examined by metallography, SEM, EDS, EPMA and IMMA. The precipitated phases of (Nb, V, Ti), (C, N), and the intermetallic compounds or eutectic phases of Fe-P, La-P, La-Sn, Ce-Sb were determined by means of TEM, SEM, EDX and EPMA [2–6]. Rare earths segregated at the grain boundary or the inner grains were detected by ion microprobe mass spectra analysis [7]. The internal friction spectrums of the rail steels were tested by NH-I-12 high temperature GE SHI pendulum [8].

3. Modification of inclusions and deep purifying steel

Micro RE could play an important role on the shape control and the modification of inclusion in clean steels, which not only on elongated MnS inclusion, but also on stringer brittleness oxides. Fig. 1 showed that the elongated MnS inclusions were controlled into the globular RE_2O_2S (Fig. 2) in the clean weather resistance steel (O: 0.0024, S: 0.004 wt.%) with RE.

When total oxygen in steel about 0.001%, the sulfur content was decreased quickly (from 0.008 to 0.002%), 2 min after adding RE.

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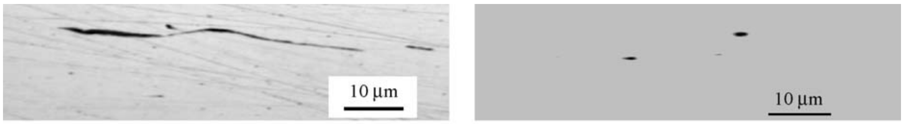


Without RE With RE, RE/S=0.63

Fig. 1. Morphology of inclusions (SEM).

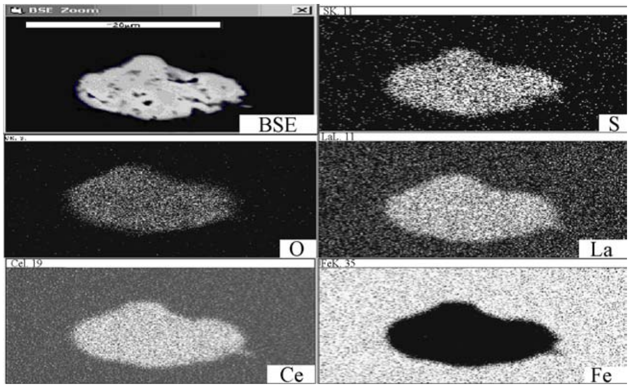


Fig. 2. EPMA of RE_2O_2S inclusion.

RE can play another important role in depressing deleterious effects of low melting point metals in steels, such as Sb, Sn, As etc. in the way of fixation of tramp elements (Fig. 3), and minimising amount of Fe-P phase [5,6,8].

4. Effect of RE on micro-alloying in the clean steels

Based on the results of dissolved rare earth metals in the low alloying steels by systematic investigation, it was found that there exists a critical point (RE/S = 2.0). The dissolved content of rare earth metals ascended quickly after MnS was completely modified, as shown in Fig. 4.

The dissolved contents of rare earth metals could be increased by the contents of the amounts of dissolved Nb, Ti or Al in steels [7].

The dissolved rare earths appeared in the grain boundary more than in the inner grain, as given in Table 1. The grain boundary was cleaned by the dissolved rare earths [7]; thereby the strength and toughness of steels were improved, as shown in [2,10].

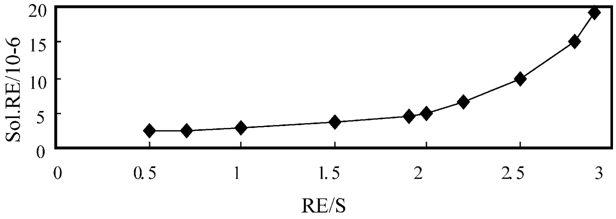


Fig. 4. Relationships between RE solid solution and RE/S in steel 16 Mn.

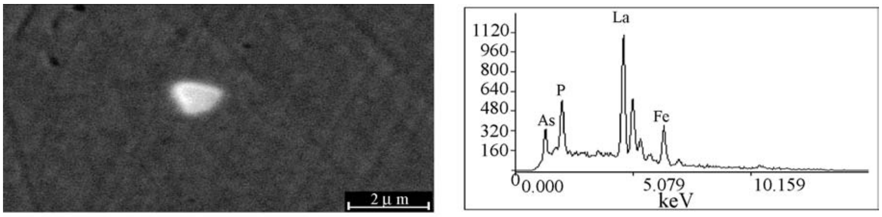
Table 1
Dissolved RE contents in steel tested by IMMA [7]

RE wt.%	Solid dissolved RE ($\mu g \times g^{-1}$)	Grain boundary I^+Ce/I^+Fe	Inner grain I^+Ce/I^+Fe
0	0	0	0
0.011	35	0.61	0.20
0.014	76	0.81	0.40
0.023	132	0.92	0.66

Influence of RE on interplanar distance of α-Fe and Fe_3C in T6 steel was shown in [9]. The effect of RE in solid solution on interplanar distance of Fe_3C was more obvious than on that of α-Fe. It has be proved that the dissolved rare earths appeared in the Fe_3C more than in the α-Fe, and resulted in deformation of the crystal lattice in cementite.

The precipitation phases were dispersed, refined, thinned and globularized promptly by the dissolved rare earths in steels. And the results of X-ray and carbon extraction replica TEM of samples proved that these precipitated particles were niobium-titanium carbonitrides, as shown in Fig. 5 [2]. Fig. 6 presented effect of rare earth content on transverse impact energy in low sulfur Nb-Ti-bearing steel, and it showed that there exists an optimum rare earth content.

The relationships between RE/S and the corrosion rate were shown in [2], and there also exists an optimum RE/S value for a specific impurity of the weather resistance steel. The results of the inner rust layer in the weather resistance steel showed that rare earths was enriched in the interphase



(a) (b)

Fig. 3. SEM of La-As-P phase (a) SEM (b) EDS.

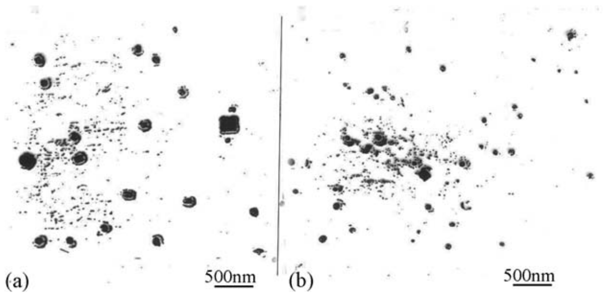


Fig. 5. Carbon electroextraction replica of precipitates, (a) RE: 0; (b) RE: 0.014%.

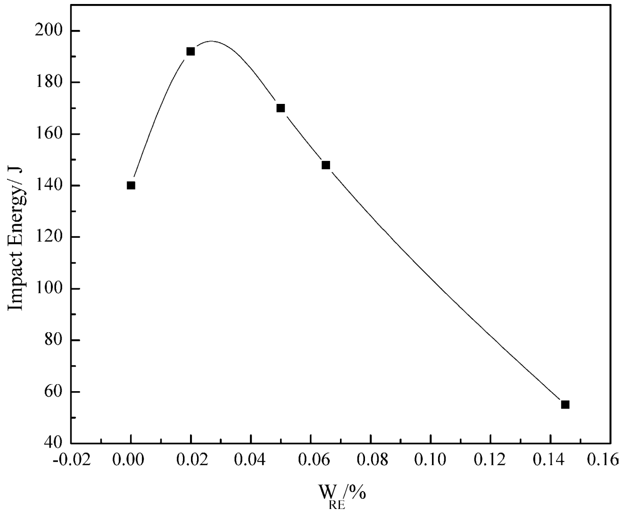


Fig. 6. Effect of RE content on transverse impact energy at −20 °C [3].

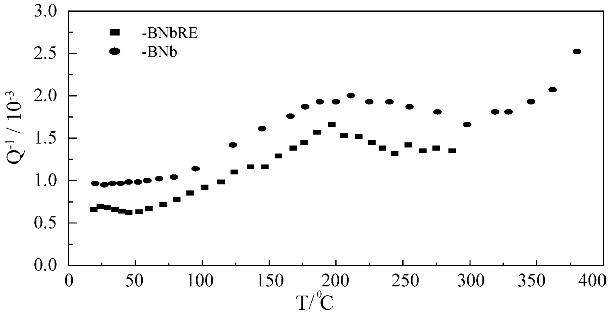


Fig. 7. Internal friction for the commercial rails [8].

between the inner rust layer and the steel substance, and that Si^{4+}, P^{5+} and Cu^{+} ions were enriched in the inner rust layer. Finally the dense composite rust layer containing Si^{4+}, P^{5+} and RE^{3+} was formed, and the property of the corrosion resistance was improved by rare earths, as shown in [2].

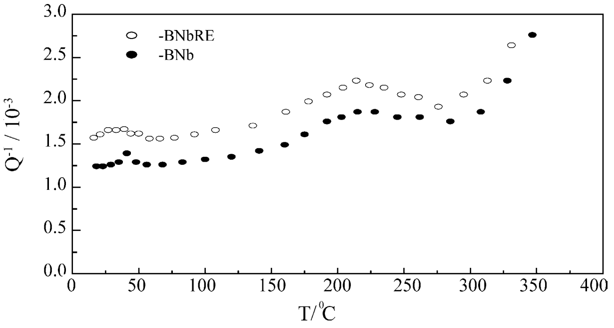


Fig. 8. Internal friction in the specimens [8].

Fig. 7 showed Snoek peak of the internal friction was enhanced by RE at room temperature for BNbRE that means RE increased carbon solubility in ferrite. Peak of SKK was weakened by RE around 473 K for BNbRE rail steel indicated that stress created by Fe_3C in ferrite reduced, as shown in Fig. 8.

The spaces between the pearlite layers were thinned for BNbRE rail steel, as shown in [8]. The property of abrasion resistance and the life of fatigue in the RE-heavy rails steel were improved by rare earths, as shown in [11].

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