# SURFACE MODIFICATION ON STEEL BY RARE EARTH AND LASER TREATMENT①

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**ABSTRACT** Several coatings including RE were treated by Laser Rapid Solidification Processing (LRSP). The RE content in the melted surface layer and the surface properties modified by RE and laser treatment on steel were studied. The experimental results show that oversaturated RE was dissolved into the steel surface layer and the steel surface treated by combining RE and LRSP has even higher wear resistance and oxidation resistance than that treated by only LRSP.

**Key words** rare earth laser treatment surface modification

## 1 INTRODUCTION

The application of Rare Earth(RE) in steel has been studied for some dozens of years. The hot-forming, founding and mechanical properties of some high alloy stainless steels were improved by RE treatment in The Carpenter Corporation of America[1]. The high impact strength of armoured steel was obtained by adding RE in America Steel Foundaries[2]. After these two kinds of difficulties in steels were overcome, the applications of RE have been receiving extensive attention of steelmaking circles. The RE also has been successfully used for developing new VAN80 high strength low alloy steel with the improvement of transverse strength by controlling the sulfide morphology at the Jones & Lawghlin Steel Corporation in America in 1968[3]. At the same time, Попова[4], Stephens *et al*[5, 6] began to study surface treatment on steel by RE. Since 1979, the progress on the studies of surface treatment with RE at home and abroad[7-10] has given a great impetus to the application and the research of RE in surface engineering. In this paper, several coatings including RE were treated by laser rapid solidification processing. It is shown that oversaturated RE was dissolved into the steel surface, and that the microstructure with laser treatment, the lattice and grain boundaries strains with the oversaturated RE have significant effects on the surface properties of the steel.

## 2 EXPERIMENTAL

The base material used in the present work was A3 steel composed of 0.16% C, 0.17% Si, 0.37% Mn, 0.016% P and 0.028% S (mass fraction). The sample size is 100 mm × 50 mm × 8 mm. The coating materials are three systems of powder; C-N-B-Ti, Ni-Cr-B-Si and RE-Si-Fe. The composition of the RESiFe powder is composed of 35.3% RE(La, Ce, Pr, Nd), 35.72% Si, 1.5% Ca and Fe (mass fraction). The binder is mixed up by several sorts of organic solvent. The powder was mixed with the binder into paste and then the paste was coated on the clean surfaces of the basic materials. The laser melting tests were carried out with a $CO_2$ Laser in

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purified Ar gas atmosphere . The rated power is 5 kW. The faculous diameter is 3 mm. The focal distance is 320 mm. In the overlaping test, the interval is 1.5 mm. The content and distribution of RE(La, Ce, Pr, Nd) along the depth beneath the melt zone surface were examined by electron microprobe. The phases of these spectrum surfaces were ascertained using X-ray diffraction. The dry wearing and the cyclic oxidation tests were employed to measure the properties of the modified surface.

## 3 RESULTS AND DISCUSSION

### 3.1 Electron probe quantitative microanalysis

Fig. 1 shows RE(La, Ce, Pr, Nd) distribution curves against the depth of the melt zone surface by the electron probe microanalysis(EPMA). From quantitative electron microprobe analysis of the reaction layer, it is found that the RE was dissolved into the steel surface. The content of the RE is almost homogeneously distributed along the depth of the melted layer and the depth of RE is similar to the melt depth. It is ~ 4% for RESiFe coating treated by LRSP, ~ 0.35% for C-N-B-Ti+ RESiFe coating and ~ 5.5% for Ni-Cr-B-Si+ RESiFe coating. The distribution of the RE with laser treatment is not the same as that of the RE diffusion-infiltrated, in which there exists a concentration gradient. The concentration gradient can induce property change. The homogeneous distribution is beneficial to improve the surface properties. Because the crystal grains become quite fine by RE and laser treatment, the grain boundary density increases greatly. Therefore, Laser Rapid Solidification can increase not only the oversaturated RE content dissolved into the crystalline(included in the grain interior and at the grain boundaries), but also the RE content at the grain boundaries. In addition, the added content of RE is related to the nature of the coating alloy system. This problem remains to be investigated further.

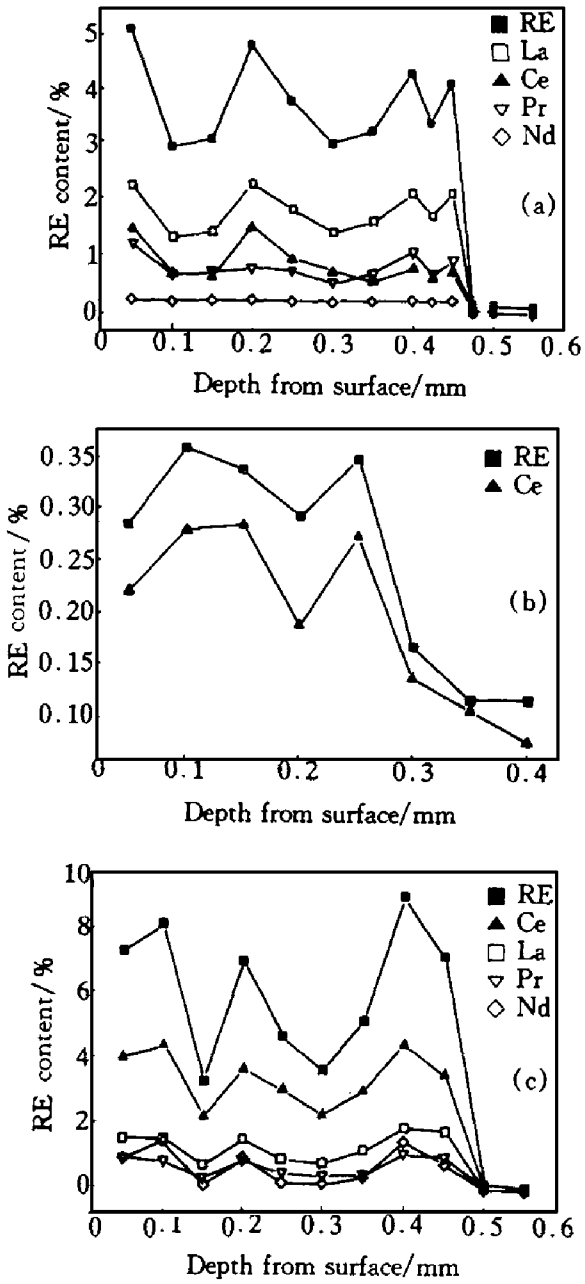


**Fig. 1 RE distribution curves by electron microprobe**

(a) —RESiFe; (b) —C-N-B-Ti+ RESiFe; (c) —Ni-Cr-B-Si+ RESiFe

### 3.2 X-ray diffraction analysis and optical micrograph of melt layer

The results of X-ray diffraction of different coatings are shown in Table 1. It is found that a part of the RE melted in the steel surface layer by LRSP has compounded RE oxides and RE intermetallic compounds and led to some changes of the steel surface properties. Fig. 2 shows the metallographs of different coatings after laser treatment. Though the grains can be refined by LRSP, the columnar grains still appear without RE. But columnar grain can disappear completely when the RESiFe is melted into the steel surface layer. A homogeneous microgranular struc-

**Fig. 2 Metallographs of different coatings**
(a) —RESiFe; (b) —C-N-B-Ti+ RESiFe;
(c) —Ni-Cr-B-Si+ RESiFe

true is obtained in the melt layer.

**Table 1 X-ray diffraction of different coatings**

| Coatings | RESiFe | C-N-B-Ti + RESiFe | Ni-Cr-B-Si + RESiFe |
|---|---|---|---|
| Main phases | α-Fe(Si)<br>$RE_2O_3$<br>RESi | α-Fe<br>$N_{23}(C,B)_6$<br>$RE_2Si_2O_7$ | α-Fe(Ni, Si)<br>$Ni_3(C, B, Si)$<br>NiB $RE_2Fe_{17}$<br>γ-Ni(Si) |

### 3.3 Wear test and cyclic oxidation kinetic test

The results of the wearing tests of the samples of the A3 steel without laser treatment, A3 steel with laser treatment, the C-N-B-Ti coating, the C-N-B-Ti+ RESiFe coating, the Ni-Cr-B-Si coating and the Ni-Cr-B-Si+ RESiFe coating by laser treatments are shown in Fig. 3. The wear-resistance of the specimens with the C-N-B-Ti+ RESiFe and the Ni-Cr-B-Si+ RESiFe treated by laser are the best, the C-N-B-Ti and the Ni-Cr-B-Si are junior, A3 only treated by laser is junior again and A3 without treatment is the worst. The first real cause is that the oversaturated RE content in the grain interior and at the grain boundary causes the great crystal lattice and grain boundary strains. The second is that the grains were refined by RE and laser.

Fig. 4 shows the cyclic oxdiation behaviours of these specimens with the C-N-B-Ti, C-N-B-Ti+ RESiFe systems and Ni-Cr-B-Si, Ni-Cr-B-Si+ RESiFe systems by laser treatment. From the cyclic oxidation kinetic curves of these reactive layers, it is found that the oxidation resistance of the steel surface only treated by laser is much higher, and the oxidation resistance of the steel treated by laser and RE is much higher. For the C-N-B-Ti+ RESiFe system, the basic mechanism is that the grains are refined and the microalloyed RE is oxidized at first. However, for the Ni-Cr-B-Si+ RESiFe system, the basic mechanism is that the RE of intermetallic com-

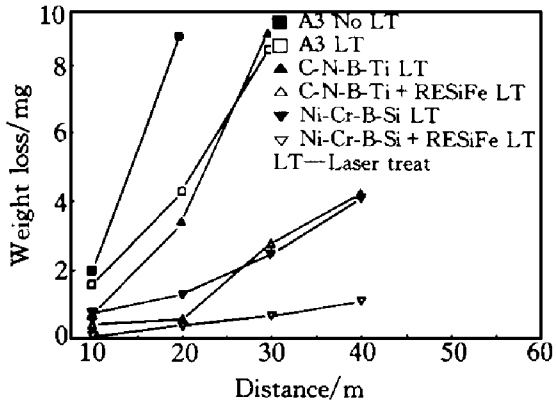


**Fig. 3 Dry wearing test**

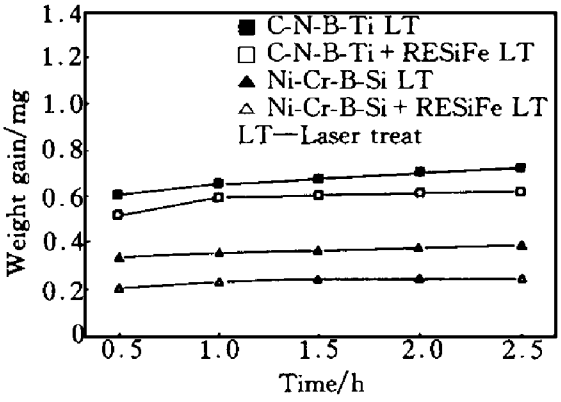


**Fig. 4 Cyclic oxidation kinetic curves at 873 K in air**

pound $RE_2Fe_{17}$ resolved and becomes the source of diffusion-oxidation layer at high temperature[12].

## 4 CONCLUSIONS

(1) The oversaturated RE can be dissolved into the steel surface layer when the surface precoatings including RE were treated by LRSP. The content of RE in the melted layer is ~ 4% for the RESiFe coating, ~ 0.35% for the C-N-B-Ti + RESiFe coating and ~ 5.5% for the C-N-B-Ti+ RESiFe coating.

(2) The RE is homogeneously distributed along the depth of the laser melted layer. The microstructure of the melted layer is homogeneous.

(3) The wear-resistance and oxidation-resistance of the steel surface layer treated by RE and LRSP technique are increased obviously.

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