Changes of inclusion, texture and magnetic property of non-oriented Si steel treated by Ca alloy

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Abstract: Based on the industrial production of non-oriented Si steel, Ca treatment by Ca alloy adding during the RH refining process was studied. The changes of inclusion, crystal texture and microstructure, and its effect on magnetic properties of final steel sheets were analyzed. The results showed that, in present work, Ca treatment can improve the texture proportion of {110} and {111} significantly, and the formation of MnS and AlN inclusions were restrained. Meanwhile, the recrystallization effects of hot rolled strip get bad and the fiber structure enhanced obviously. The grain size of finished steel sheets increased as the increase of Ca alloy adding amount quickly, and then decreased. Compared with the non-Ca treatment charge, the numbers of inclusions whose size below 1.0μm will decrease by 68.06%, 87.50% and 94.94%, the texture proportion of {110} and {111} was 30.3%, 39.1%, 17.6% and 2.8%, 5.5%, 20.6%, while the correspondent Ca alloy adding amount is 0.67 kg/t steel, 1.00 kg/t steel and 1.67 kg/t steel, respectively. In addition, the core loss gradually decreases to a stable level as the increasing of Ca added, and the magnetic induction decreases quickly after slow increasing, respectively. The optimal Ca treatment mode depends on the chemical compositions of steel grades.

1 Introduction
The demands for energy saving and environment protection are more and more increasing recent years. Various kinds of EI core, motor, compressor are being developed toward smaller scale, and higher efficiency [1]. Thus, as raw material of the cores, the non-oriented Si steel with excellent magnetic properties [2], is required to fulfill the strong demand for energy saving and high efficiency of the electric power consuming products. The magnetic properties of non-oriented Si steel mainly depend on the grain size of ferrite, crystallographic texture, and the inclusions in the steel [3-4].

The present work studied the Ca treatment by adding Ca alloy in the liquid steel during refining of Si steel in industrial production process. The morphology and size distribution of inclusions were observed. The behavior change of inclusions in Si steel after Ca treatment and its influence on the magnetic properties of finished product was discussed.

2 Experimental
2.1 Production Process
The Ca treatment was carried out by adding Ca alloy to the liquid steel during RH refining. The main composition of Ca alloy is CaSi which size is 10~50mm. The requirement of some technique parameters during LD tapping and RH refining is listed in Table 1. The main...
chemical compositions of steel used in present work are shown in Table 2.

Table 1 Requirement of technique parameters during LD tapping and RH refining

| Tapping                                      | RH refining                                    |
|----------------------------------------------|-----------------------------------------------|
| Temperature                                 | Temperature                                    |
| 1640±20 °C                                  | 1600±20 °C                                    |
| Free oxygen                                 | Ca adding                                      |
| 0.04%-0.12%                                 | 0-2.0 kg/t steel                              |
| T·Fe + MnO                                  |                                               |
| ≤5%                                          |                                               |

Table 2 Main chemical compositions of steel used in present work, mass%

| C   | Si  | Mn  | P   | S   | Al  | Ca  |
|-----|-----|-----|-----|-----|-----|-----|
| 0-0.005 | 0-2.1 | 0.2-1.0 | 0-0.2 | 0-0.005 | 0.2-1.0 | 0-0.01 |

2.2 Experimental Methods

Steel samples were taken in steelmaking process. The correspondent steel sheets of the same batch were taken. The microstructures were observed by SEM and the grain size of finished sheets was measured by intersection method. The morphologies, chemical compositions, quantities, size distribution of non-metallic inclusions were investigated by SEM and EDS. Each specimen was observed for 10 connected fields of view, an image analysis software was used to obtain the quantity and the size distribution of the non-metallic inclusions. The magnetic properties of finished steel sheet were measured by the Epstein frame method.

3 Results and discussion

3.1 Quantity and Size Distribution of Extracted Non-metallic Inclusions

The results showed that the size and numbers of non-metallic inclusion were increased in 1000 times, with the increase of Ca alloy adding amount. When Ca alloy adding amount reached 1.67 kg/t steel, the average size of non-metallic inclusion was largest and the numbers was most, and the numbers of non-metallic inclusions decreased at first and then increased in 5000 times, and some of the non-metallic inclusions was relative larger. The size distribution of these non-metallic inclusions was obtained from SEM photos by imagine analysis software, as shown in Fig.1. The size of most inclusions in finished Si steel sheet without Ca treatment is that whose size was smaller than 1.0 μm, the numbers was 1.6×10⁷/mm³; and the numbers of inclusions in finished Si steel sheet with Ca treatment sharply decreased, especially the fine inclusions whose size was smaller than 1.0 μm. Furthermore, the fine inclusion was still decreased with the increase of Ca alloy adding amount, but the change was rather small. Compared with the charge without Ca treatment, the numbers of inclusions whose size below 1.0μm decrease by 68.06%, 87.50% and 94.94%, while the correspondent Ca alloy adding amount is 0.67 kg/t steel, 1.00 kg/t steel and 1.67 kg/t steel, respectively.

3.2 Types of Non-metallic Inclusions

The fine inclusions MnS and Cu₅S will not disappear even the Ca alloy adding amount reached to 1.67 kg/t steel and is relate to the lower Ca element, and the weak combine of Ca and S. The precipitation of fine MnS and Cu₅S is either single, or precipitation as the core of AlN and combined to the component inclusions [5-6]. The fine inclusions of MnS and Cu₅S exist single, or combined with AlN and CaS under different Ca treat condition in the range of 1-5 μm, and the CaS inclusion has been found after Ca treat in the above size range. That showed that some Ca will combine with S, and the S can’t be floated and removed immediately after the Ca alloy adding into the liquid steel. When the Ca alloy adding amount reached 0.67 kg/t steel, there are still some MnS and AlN appeared in the finished steel sheets; when the Ca alloy adding amount reached 1.00 kg/t steel or 1.67 kg/t steel, the main type of inclusions is oxysulfide of Ca in the finished steel sheets. Because of the distortion and extension of MnS in the processes of cold rolling and annealing, the recrystallization of finished steel will be retard seriously, and decrease the magnetic properties of finished steel sheets. Meanwhile, according to the Zener formula [7], the inhibitor force on the grain
boundary is proportional to the volume fraction of inclusions, and inverse to the average radius of inclusions. Thus, from the viewpoint of improving the magnetic properties, in order to obtain the excellent controlling effects of inclusions, it is better to choose the suitable Ca treat method to decrease the numbers and increase the size of inclusions [8].

![Fig. 1 Size distribution of inclusions from Si steel sheets with and without Ca treatment](image)

### 3.3 Microstructures Heredity

The relation between grain size before and after SRA and the Ca concentration is shown in Fig 2. The grain size of steels with Ca alloy adding amount was 0.67 kg/t steel and 1.00 kg/t steel are almost same before SRA (31.5 μm and 34.3 μm, respectively), but the later was more easy to grow after SRA (38.4 μm and 48.7 μm, respectively). But when Ca concentration reached 1.67 kg/t steel, the grain size of finished product are almost same as that without Ca treatment probably due to the grain refinement effect of CaS.

![Fig. 3 Relation between grain size before and after SRA and the Ca adding amount](image)

### 3.4 Crystal Texture of Finished Steel Sheets

It is harmful to the magnetic properties, due to the {111} plane of more grain is parallel to the rolling plane. So, in order to improve the magnetic properties of finished steel sheets, the heat treating should be adopted to improve the proportion of the grain whose {100} and {110} plane paralleled to the rolling plane, and replace the {111} and {112} plane by the {100} and {110} plane. In present work, we can see that, the proportion of {100} is decreased, and the proportion of {111} is increased with the increase of Ca alloy adding amount, and the proportion of {110} is increased slowly at first, and then decreased sharply with the increase of Ca alloy adding amount. The texture proportion of {110} and {111} was 30.3%, 39.1%, 17.6% and 2.8%, 5.5%, 20.6%, while the correspondent Ca alloy adding amount is 0.67 kg/t steel, 1.00 kg/t steel and 1.67 kg/t steel, respectively. The ODF graphs are showed in Fig 3.

![Fig. 3 Change of texture proportion of Si steel with Ca adding amount](image)
3.5 Magnetic Property of Finished Steel Sheets

The core loss and magnetic induction flux density were measured for Si steel sheets with different Ca treatment condition before and after SRA as shown in Fig. 4. From Fig. 4, we can see that the core loss decreases with the increase of Ca concentration and tends to stable, the magnetic induction flux density increases with the increase of Ca concentration and then decreases. This is because that the number of fine inclusions decreased by Ca treatment so the grains grown easily during SRA, resulted the decrease of core loss. But the mechanism of magnetic induction flux density change with Ca treatment seems complicated, it needs further studies [9]. Moreover, it is clear that the core loss after SRA decreased quickly and attained a minimum value when Ca concentration was at 1.00 kg/t steel then increased. This can be explained according with the relation between grain size and Ca concentration, as shown in Fig.2.

![Graphs showing the change in magnetic properties of Si steel before and after SRA](image)

(a) Before SRA  (b) After SRA

Fig. 4 Change of magnetic properties of Si steel with Ca adding amount before and after SRA

4. Conclusions

Following conclusions can be summarized: (1) Ca treatment can improve the texture proportion of \{110\} and \{111\} significantly, and the formation of MnS and AlN inclusions was restrained. Meanwhile, the grain size of finished steel sheets increased as the increase of Ca alloy adding amount quickly, and then decreased. (2) Compared with the non-Ca treatment charge, the numbers of inclusions whose size below 1.0μm will decrease by 68.06%, 87.50% and 94.94%, the texture proportion of \{110\} and \{111\} was 30.3%, 39.1%, 17.6% and 2.8%, 5.5%, 20.6%, while the correspondent Ca alloy adding amount is 0.67 kg/t steel, 1.00 kg/t steel and 1.67 kg/t steel, respectively. (3) In addition, the core loss gradually decreases to a stable level as the increasing of Ca added, and the magnetic induction decreases quickly after slow increasing, respectively. The optimal Ca treatment mode depends on the chemical compositions of steel grades.

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