6.5wt% Si Electrical Sheet Produced by Laminar Composite Technique with Thermo-mechanical Process

Shuai Ji
School of Materials Science and Engineering, Xi’an Shiyou University, 18Dianzier Road, Xi’an, Shaanxi, 710065, PR China
carven0910@sina.com

ABSTRACT: Fabrication of 6.5wt% Si electrical thin sheet by laminar composite technique and thermo-mechanical process was presented in this article. Morphology and elements content variation over thickness of each layer of the composite plate contains outer, transition and inner layers are investigated respectively during different stages of deformation and heat treatment procedures. Iron loss value of the homogeneous sheet was measured after diffusion annealing and a series of gradient high silicon electrical steels could be obtained by controlling the diffusion route.

KEYWORDS: 6.5wt% Si composite; Clad casting; Thermo-mechanical process; Diffusion annealing; Iron loss.

1. INSTRUCTIONS

Base on well electrical characteristics of soft magnetic material, high silicon steel is widely used as transformers, motor cores and other electrical devices. Magnetic properties of this alloy can be improved as silicon amounts increasing\(^1\)\(^-\)\(^4\), however, this material becomes obviously hard and brittle with silicon content improving and is difficult to obtain by conventional rolling routes. Especial for 6.5wt% Si electrical steel, it exhibits excellent soft magnetic properties such as low iron loss, near-zero magneto striction and so on. In order to produce 6.5wt% Si electrical steel and avoid rolling troubles, several approaches have been developed like chemical vapor deposition (CVD)\(^5\), hot dipping and diffusion annealing\(^2\), direct powder rolling (DPR)\(^6\) and spray forming\(^7\), etc. Preparation of 6.5wt%Si electrical thin sheet by laminar composite technique and combining thermo-mechanical processes with heat treatment is reported in this research.

2. EXPERIMENTAL

Raw materials of this experiment are industrial silicon block (99wt%Si) and Q235 low carbon steel whose composition contains 0.15C, 0.01S, 0.03Mn, 0.01P, 0.0045O, 0.07Al, and balance Fe. The three-layer composite ingot approximate 10kg was obtained by clad casting in a vacuum induction furnace. Hot rolling process was performed after hot forging of the ingot. This composite plate got warm rolled after proper heat treatment as hot rolling finished. Its iron loss was measured as the composite sheet has transformed into the homogeneous steel by diffusion annealing.

3. RESULTS AND DISCUSSION

3.1 Coat casting

According to the plan of producing 6.5wt% Si composite alloy the authors designed, construction of this material is like a three-layer sandwich hamburger as shown in Figure 1. Melting procedures are consisted of two stages, the former one is preparation of core layer whose silicon amount is approximate 10wt% in a given mold and the latter one is clad casting. A transition layer between outer and inner layers is created by metallurgical bonding in terms of high temperature.

3.2 Hot deformation

The composite ingot with thickness 70mm was heated at 1150°C for 1h and then got forged into 40mm. Aim of forge is to reduce defects generated in
melting, refine large columnar grains and improve metallurgical bonding of layers. Hot rolling ranges 800-1150°C, because of avoiding extreme brittleness and hardness of core layer at low temperature. The total passes reduction is about 95% and thickness of the composite plate is approximate 2.0mm. The hot rolling procedure contains two parts by virtue of limitation of the furnace capacity. Microstructure of the composite plate after hot rolling in the first step is shown in Figure 2a. Grains of outer layer are equiaxial and fine, due to temperature of hot rolling ending is higher than that of recrystallization and time for grain growth is insufficient. Grain size of core layer is about 200-300μm and ordered organizations have been observed in grain interior whose silicon concentration is rich. Morphology of the composite plate at the end of the second hot rolling is shown in Figure2b. The microstructure of grains of outer and transition layers are as same as the first step of hot rolling, respectively. More cracks have been appearing in grains interior of core layer. This phenomenon indicates that elimination of residual stress is insufficient, due to the composite plate thickness becomes thinner than before which induces more thermo energy dissipation. There is a certain diffusion occurrence during the hot rolling in terms of low level of silicon content in outer layer as shown in Figure 3. It is good for the core layer to be protected by the clad layer during deformation process in light of the thicker transition layer.

3.3 Warm rolling

Microstructure diagram of the sample after warm rolling is observed as shown in Figure 4. Grains of outer layer are equiaxial, and their sizes are not uniform by virtue of the different rate of grains growth. There is occurrence of recrystallization in the transition layer where is adjacent with the clad layer. Several elongated grains are observed in which is near the inner layer and also their sizes are different with others. Grains of core layer are coarse and elongated significantly. The grain boundaries are clear but not parallel which aggregate in the low silicon region where a few new fine grains appearing. That indicates silicon content and deformation of grains in core layer is heterogeneous. There is no crack appearance during warm rolling in light of the proper temperature, passes reduction and reheat frequencies. Several 6.5wt%Si composite plates become thin sheet with thickness about 0.3-0.45mm at the end of warm rolling and the elements content over thickness are investigated. Reheating at high temperature is performed several times during warm rolling, and that induces a certain oxidation at the surface of outer layer as the red curve shown in Figure 5.

3.4 Diffusion annealing

The 6.5wt%Si composite sheet after warm rolling is homogenized to become a homogeneous sheet by diffusion annealing at 1200°C. Thickness of the sample is from 0.35mm to 0.4mm after homogeneous treatment at 1200°C for 45min as shown in Figure 6. The uniform sample becomes thicker in light of grains growth after the
recrystallization at high temperature. Grains are large whose sizes are near as well as the sheet thickness. Elements content variation over thickness of the sheet is investigated as shown in Figure 7.

Figure 6. Microstructure of 0.4 mm composite sheet after diffusion annealing at 1200°C for 45 min.

Figure 7. Elements concentration variation over thickness of 6.5 wt% Si composite sheet after diffusion annealing.

3.5 Magnetic Properties

Iron loss values of some samples homogenized are investigated as shown in Table 1. In order to obtain better values, both thickness of sheet and anisotropy of grains should be decreased and as well the cold rolling route should be carried out after diffusion annealing and subsequent heat treatment.

Table 1. Iron loss measurement of two groups of composite samples homogenized by diffusion annealing.

<table>
<thead>
<tr>
<th>Thickness (mm)</th>
<th>Iron loss (W/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W10/50</td>
</tr>
<tr>
<td>0.35</td>
<td>2.03</td>
</tr>
<tr>
<td>0.45</td>
<td>3.07</td>
</tr>
</tbody>
</table>

4. CONCLUSION

In terms of sufficient temperatures, proper deformation routes and heat treatments, thermo-mechanical forming of 6.5 wt% Si composite plate fabricated by clad casting is possible by conventional rolling processes. This composite plate can be homogenized to be a uniform sheet as well as its grain size be controlled by diffusion annealing parameters in order to get better magnetic characteristics. It could also get a series of gradient high silicon steels by controlling the same parameters.

5. ACKNOWLEDGEMENTS

The author would like to thank the financial support from Xi’an Shiyou University Materials Science and Engineering Provincial Financing Advantage Disciplines.

REFERENCES