[54] METHOD FOR MANUFACTURING
GRAIN-ORIENTED ELECTRICAL STEEL
SHEET AND STRIP IN COMBINATION
WITH CONTINUOUS CASTING

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75/123 L; 164/76; 29/527.7

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Primary Examiner—Lowell A. Larson
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Stanger

[57] ABSTRACT

A method for manufacturing grain-oriented electrical
steel sheet and strip having excellent and stabilized
magnetic characteristics in the rolling direction by
continuous casting, in which a continuously cast steel
slab containing 0.005–0.06 percent of C, not more
than 4.0 percent of Si, 0.030–0.090 percent of Mn and
0.010–0.030 percent of S is, after heating to a tempera-
ture from 1250°C to 1350°C, hot rolled continuously
under the condition that the material is kept for
30–200 seconds in the temperature range between
1200°C and 950°C, and then the material is cold rolled
and annealed.

1 Claim, 3 Drawing Figures
**FIG. 1**

Components: C 0.035-0.046\%, Mn 0.047-0.060\%, S 0.016-0.018\%
Slab heating temperature: 1300°C
Thickness of the product: 0.30 mm

**FIG. 2**

Components: C 0.035-0.043\%, Mn 0.045-0.060\%, S 0.016-0.018\%
Slab heating temperature: 1300°C
Thickness of the product: 0.30 mm

**FIG. 3**

Temperature range of effective MnS precipitation
METHOD FOR MANUFACTURING
GRAIN-ORIENTED ELECTRICAL STEEL SHEET
AND STRIP IN COMBINATION WITH
CONTINUOUS CASTING

The present invention relates to a method for manufacturing grain-oriented electrical steel sheet and strip having crystal grains with the orientation of (100)[001] by utilizing a continuously cast slab. For the use as a grain-oriented electrical steel sheet and strip, it is important that the metal possess excellent magnetic characteristics i.e. that, the magnetization characteristic (the relation between the magnetic field intensity and the magnetic flux density) and the iron loss characteristic (the relation between the magnetic flux density and the iron loss) are excellent. It is required that the magnetic flux density as a magnetization characteristic (expressed generally by $B_h$ value) is high, and the iron loss (expressed generally by $W_{1700}$ value) is low.

It has been known that, while the iron loss of the material is influenced by the composition of the steel, the grain size, impurities, inclusions, residual stress, etc., the value can also be reduced by improving the magnetization characteristic, i.e., $B_h$. Steel sheet and strip having high $B_h$ value possess a favourable iron loss particularly in the high magnetic flux density region.

Therefore, improving the magnetization characteristic is effective not only for the reduction of iron loss, but also to minimize the size of various electrical instruments, such as, transformers, by lightening the weight of iron core used thereafter.

Now, as it is well known, the method for manufacturing steel has been changing rapidly from the conventional ingot making which has been replaced more and more in recent years to continuous casting. The continuous casting method is advantageous since the yield is improved, and the blooming step is omitted. Moreover, the method is particularly useful in the manufacture of high class steels.

Steel plates manufactured by continuous casting have also possess superior surface shape and appearance in general and uniformity of the chemical composition in the casting direction.

On the other hand, as for the macrostructure of a continuously casted slab, while the surface and core parts consist of granular grains, a greater part of the intermediate portion is formed of columnar grains, and moreover, a dense segregation zone of sulfur, called black band, exists at the central part in the direction of the slab thickness.

The columnar crystals in the continuously casted slab for use as grain-oriented electrical steel sheet and strip grow abnormally when the temperature is high (i.e., above 1350°C) in heating the slab for hot rolling, give an abnormal structure in the stage of primary recrystallization annealing after the hot and cold rolling, and change to so called fibrous fine grains in the final secondary recrystallization annealing, thus deteriorating the magnetic characteristics.

To improve the magnetic characteristics in the grain-oriented electrical steel sheet and strip, it is important in general, in the final annealing, to control the normal growth of the primary recrystallization grains and to develop the secondary crystallization grains having the orientation of (110)[001]. The existence of suitable fine dispersed particles is an important factor for this purpose.

However, the sulfur existing as a dense segregation zone in the continuously cast slab disperses and dissolves as a solid solution in the steel thus causing difficulties in heating the slab. This is a severe drawback in the manufacture of grain-oriented electrical steel sheet and strip in which MnS formed between S and Mn is utilized as fine dispersed particles.

It is thus seen that in manufacturing grain-oriented electrical steel sheet and strip which possesses excellent magnetic characteristics in the rolling direction by utilizing the continuous casting method, it is necessary to heat the slab in the temperature range where no abnormal growth of columnar grains takes place in the heating before the hot rolling, and moreover, to dissolve the MnS which has precipitated as large particles in the slab completely in the steel to form a solid solution in said temperature range. MnS in the dense segregation zone of sulfur is hard to dissolve in a solid solution, and thus causes difficulty in forming the fine dispersed particles which are effective in the secondary recrystallization. Therefore, the control of MnS in the continuously cast slab is more important.

The present inventors have succeeded in manufacturing grain-oriented electrical steel sheet and strip by utilizing continuous casting, in which MnS is utilized as effective fine dispersed particles for the development of the secondary recrystallization grain. This results in the production of grain-oriented electrical steel sheet and strip having consistently excellent magnetic characteristics by assuring that the MnS is dissolved in the steel as a solid solution sufficiently in the heating stage of the slab and is precipitated effectively in the hot rolling stage of the material.

The present invention provides a method for manufacturing grain-oriented electrical steel sheet and strip having stabilized high magnetic characteristics in the rolling direction, characterized in that a continuously cast slab containing 0.005 - 0.06 percent of C, not more than 4.0 percent of Si, 0.030 - 0.090 percent of Mn and 0.010 - 0.030 percent of S is, after heating to a temperature from 1250°C to 1350°C, hot rolled continuously under the condition that the material is kept for 30 - 200 seconds at a temperature between 1200°C and 950°C, and then the material is cold rolled and annealed.

As for the control of MnS in the manufacture of grain-oriented electrical steel sheet and strip, it is stated in Japanese Patent Publication Sho 36-3352 to W. C. Fiedler that MnS is dispersed as fine particles uniformly in cast steel by cooling the cast steel rapidly from the molten state of sulfide to 800°C in the course of solidifying molten steel, and thus the formation of secondary recrystallization grains having (110)[001] orientation is accelerated.

On the other hand, it is stated in Belgian Patent No. 747,197 to Kohler that the magnetic characteristics are improved when the cooling rate is as small as possible in casting the steel continuously. Although the conclusions on the direction of cooling rate are reversed in the two arts, the importance of the cooling rate is similarly pointed out.

The two prior arts relate to controlling MnS in the solidification of molten steel, and, as for the method of controlling MnS in the slab and other already solidified...
materials, only the method of controlling the slab heating temperature is found in the prior art. The present invention is to control the behavior of MnS by cooling the continuously cast slab slowly in the course of hot rolling, and this is a quite different technical idea from the conventional art.

The details of the invention will be explained in the following.

The starting material for the manufacture of electrical steel sheet and strip in this invention is a steel slab, for whose manufacture, molten steel which is smelted by a known steel making method, for instance, in a converter or an electric furnace, is solidified by a continuous casting method.

It is necessary that the components in the slab of this invention satisfy the following conditions:

C : 0.0050 - 0.060%
Si: not more than 4.0%
Mn 0.030 - 0.090%
and
S : 0.010 - 0.030%.

The amounts of Mn and S decide the amount of MnS as fine dispersed particles which is important for the grain growth in the secondary crystallization. When the amounts of Mn and S are less than the above-mentioned ranges, the absolute amount of MnS as fine dispersed particles is insufficient for the secondary recrystallization, and no satisfactory grain growth in the secondary crystallization can be attained.

On the other hand, when the amounts of Mn and S are larger than said ranges, the size of MnS becomes too large and such MnS can not form a solid solution sufficiently in the heating temperature range of the slab as defined in this invention, and consequently, the shape, size and dispersion of the dispersed precipitate in the hot rolling become unsuitable. As a result, no satisfactory grain growth takes place in the secondary recrystallization by using such a precipitation dispense phase.

As above explained, without the range of the amounts of Mn and S as defined, it is impossible to manufacture single-oriented electrical steel sheet and strip possessing excellent magnetic characteristics by the continuous casting method.

While the fine dispersed particles in this invention consists chiefly of MnS, a proper amount of AlN and similar compounds containing Se, Te, B and the like may also be added as the constituents in the dispersed particles.

It has been known that Si is effective to reduce the iron loss in electrical steel sheet and strip. The amount of Si in the present invention is similar to the content thereof in usual grain-oriented electrical steel sheet and strip. As cracks are formed in the cold rolling when the amount is larger than 4.0 percent, the amount of Si is defined as less than 4.0 percent.

The amount of C is defined as 0.0050 - 0.060 percent. When the amount is larger than this range, much time is required for the decarburization in the subsequent stage and it is not economical. If below this range, the secondary recrystallization proceeds with difficulty, and fine crystal grains are apt to be formed in the final product.

Now, the essential characteristic of the invention, the steps of the slab heating and continuous hot rolling will be described.

While MnS as the dispersed precipitate in this invention is already formed in the continuously cast slab before the slab is heated for the hot rolling, as MnS in this state is not uniform in its dispersion and has a relatively large size, it is necessary to dissolve the MnS in the matrix as a solid solution in the slab heating furnace. However, the problem of columnar grains exists in the continuously cast slab as above-mentioned, and, when such a slab is heated at a higher temperature (above 1350°C), the grains grow abnormally to deteriorate the magnetic characteristics of the final product. Therefore, the slab heating should be carried out at a relatively low temperature. Considering such a situation, the amounts of Mn and S are defined as above-mentioned in this invention in order to dissolve the MnS in matrix as a solid solution sufficiently in the temperature range where the abnormal growth of columnar grains does not take place. The slab heating temperature necessary to satisfy the condition depends on the amounts of Mn and S, and there exists a suitable temperature range defined in general by \[ [\text{MnS} \times \%] \]

The temperature range corresponding to the amounts of Mn and S in the present invention lies between 1250°C - 1350°C, where MnS can be dissolved sufficiently in the steel as a solid solution without the abnormal growth of columnar grains.

However, even when said condition is satisfied, the dissolution of MnS as a solid solution is still difficult at the dense segregation zone of sulfur existing in the continuously cast slab, and as a result, the dispersion state thereof after frequently does not become uniform.

MnS, once dissolved in the steel as a solid solution, is precipitated at a definite temperature range, differing somewhat depending on the amounts of Mn and S, in the course of the continuous hot rolling.

As effective fine dispersed particles for the development of secondary recrystallization grains having (110)[001] orientation, it is necessary that the dispersed particles be of a size less than 0.1μ and are dispersed uniformly with a high distribution density. It is the feature of this invention that the precipitation of MnS as above-mentioned, having a fine in particle size and dispersed uniformly with a high distribution density, is performed by utilizing the continuous hot rolling process.

In Belgian Patent No. 747,197 to Kohler, the formation of a dense segregation zone of sulfur in the continuous casting is prevented possibly by cooling the slab as slow as possible. However, in such a method, not only the productivity of continuous casting is remarkably poor, but also the process control, such as, the amount of cooling water is very difficult.

On the contrary, in the present invention, investigations have been performed on the method of manufacturing grain-oriented electrical steel sheet and strip having excellent magnetic characteristics in the state of the formation of dense segregation zone of sulfur in the continuously casted slab. As a result, grain-oriented electrical steel sheet and strip having excellent magnetic characteristics were obtained, even when a dense segregation zone of sulfur exists, by cooling the material slowly in the course of continuous hot rolling to utilize, as effectively as possible, the MnS dissolved in the steel forming a solid solution at the relatively lower slab heating temperature.

It has been ascertained that the temperature range of precipitating effective MnS is 1200°C - 930°C, and the
object is attained by keeping the material for 30 – 200 seconds at this temperature range.

The present invention will be described by referring to the attached drawings.

FIG. 1 is a graph showing the relation between the average holding temperature of the material in the continuous hot rolling process and $B_0$. FIG. 2 is a graph showing the relation between the holding period from $1200^\circ$C to $950^\circ$C and $B_0$, and FIG. 3 is a graph showing some examples of the cooling patterns.

FIG. 1 shows the relation between the average holding temperature of the material and the magnetic flux density $B_0$ when the material is kept for a definite period in the range before the (45 sec.) finish rolling in the continuous hot rolling process of a slab after heating the slab at a temperature $1250^\circ$C – $1350^\circ$C.

As obvious from the figure, a high magnetic flux density $B_0$ is obtained when the holding temperature is in the range of $1200^\circ$C – $950^\circ$C. This is because the effective MnS is precipitated only when the holding temperature lies in the range of $1200^\circ$C – $950^\circ$C.

FIG. 2 shows the relation between the holding period of the material in the temperature range from $1200^\circ$C to $980^\circ$C when the slab heated at a temperature $1250^\circ$C – $1350^\circ$C is cooled slowly in said temperature range before the finish rolling in the continuous hot rolling.

As evident from the figure, a high magnetic flux density $B_0$ can be obtained when the holding period is 30 – 200 seconds. When the holding period is less than 30 seconds, the precipitation of effective MnS is insufficient, and on the other hand, when the holding period exceeds 200 seconds, the MnS precipitate grows coarse and begins to aggregate. In both cases, the precipitation of MnS effective for the development of the secondary recrystallization grains having (110)[100] orientation cannot be obtained.

From the results as shown in FIGS. 1 and 2, the condition of the continuous hot rolling process in this invention is defined as keeping the slab for 30 – 200 seconds in the temperature range $1200^\circ$C – $950^\circ$C of the continuous hot rolling.

The slow cooling may be extended to the hot finish rolling process when a sufficiently slow cooling can also be performed in the hot finish rolling. However, in a usual hot rolling line where the material is cooled rapidly in the hot finish rolling process, it is advisable to perform said slow cooling in front of the hot finish rolling.

FIG. 3 shows some examples of the cooling pattern in such a hot rolling line. A distinct bend point (a) in each of the curves represent the state before the finish rolling stand. In curve (A) the finish rolling is done from about $1200^\circ$C; in the curve (B) the material is cooled slowly from $1200^\circ$C to $950^\circ$C and the finish rolling is done from $950^\circ$C, in the curve (C) the material is kept at a constant temperature in the range $1200^\circ$C – $950^\circ$C and the finish rolling is done above $950^\circ$C, and in the curve (D) the finish rolling is done from about $950^\circ$C without any slow cooling or a constant temperature treatment.

As obvious from the results, in a hot rolling line where the material is cooled rapidly in the finish rolling, the material can not be kept for 30 – 200 seconds in the temperature range $1200^\circ$C – $950^\circ$C according to the schedule in curve (A). Therefore, in such a line, the rolling should be done according to the curve (B) or (C).

In curve (D), while a temperature range $1200^\circ$C – $950^\circ$C exists before the finish rolling, as the holding period is short, the object of the present invention cannot be achieved. The curve (D) shows a typical cooling pattern heretofore.

As a practical means in applying the present invention in a continuous hot rolling process, such means, for instance, as controlling the water amount in descaling or in roll cooling, the revolution number of the roll or the number of pass times in the course of rough rolling of the slab taken out from the heating furnace, reducing the reduction of the rolling material in said stage, and increasing the thickness of the slab manufactured by the continuous casting, or the combination of these means may be adopted.

A hot rolled steel sheet containing proper MnS obtained in this way is cold rolled more than once, and subjected to a primary recrystallization-decarburization annealing and finally a finish annealing to obtain the final product.

Examples of the invention will be set forth in the following.

EXAMPLE 1

Continuously cast slabs of the same charge containing 0.041 percent of C, 3.12 percent of Si, 0.057 percent of Mn and 0.017 percent of S as ladle composition were taken out from the furnace after heating for 3 hours at $1310^\circ$C, and were passed in a continuous hot rolling process under the conditions as shown in Table 1 to obtain hot rolled steel sheets 2.3 mm in thickness. The inventive slow cooling was performed before the finish rolling.

These hot rolled sheets were cold rolled two times (the reduction in the secondary cold rolling was 55 percent) inserting an intermediate annealing for 3 minutes at $850^\circ$C to obtain final products 0.30 mm and 0.28 mm in thickness, decarburized for 3 minutes at $840^\circ$C in an atmosphere of moist $H_2$, and finally annealed for 20 hours at $1170^\circ$C in $H_2$. Magnetic characteristics of the final products in the rolling direction were as shown in Table 1.

<table>
<thead>
<tr>
<th>Slab No.</th>
<th>Slab</th>
<th>Temperature before finish rolling</th>
<th>Magnetic characteristics</th>
<th>Thickness of the final product</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>before finish rolling</td>
<td></td>
<td>Iron loss W/kg</td>
</tr>
<tr>
<td>Slab No.</td>
<td></td>
<td>in 20°C</td>
<td>before finish rolling sec.</td>
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<tr>
<td>1</td>
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<td>1.87</td>
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<td>2</td>
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<td>173</td>
<td>1.23</td>
<td>1.87</td>
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<td>3</td>
<td>987</td>
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<td>1.28</td>
<td>1.84</td>
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<td>4</td>
<td>1177</td>
<td>71</td>
<td>1.17</td>
<td>1.87</td>
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<tr>
<td>5</td>
<td>1168</td>
<td>169</td>
<td>1.18</td>
<td>1.86</td>
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<tr>
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<td>940</td>
<td>25</td>
<td>1.53</td>
<td>1.76</td>
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<td>7</td>
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<td>0</td>
<td>1.42</td>
<td>1.79</td>
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<tr>
<td>8</td>
<td>1178</td>
<td>20</td>
<td>1.44</td>
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<td>9</td>
<td>1167</td>
<td>211</td>
<td>1.45</td>
<td>1.78</td>
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</table>

EXAMPLE 2

Continuously cast slabs (200 mm in thickness) of the same charge containing 0.041 percent of C, 3.16 percent of Si, 0.053 percent of Mn and 0.017 percent of
3,872,704

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S as ladle composition were taken out from the furnace after heating for 3 hours at 1280°C, and were hot rolled continuously under the conditions as shown in Table 2 to obtain hot rolled steel sheets 2.3 mm in thickness. The slow cooling was done in a similar way as in Example 1. These hot rolled sheets were cold rolled two times (the reduction in the secondary rolling was 55 percent) inserting an intermediate annealing for 3 minutes at 840°C to obtain final products 0.30 mm in thickness, decarburization annealed for 3 minutes at 850°C in moist H₂, and finally annealed for 20 hours at 1170°C in H₂. Magnetic characteristics of the product in the rolling direction were as shown in Table 2.

As it is more clearly understood from the examples, grain-oriented electrical steel sheet and strip having quite excellent magnetic characteristics can be manufactured by utilizing a continuous casting method according to the present invention, and possess great industrial merit.

What is claimed is:

1. A method for manufacturing grain-oriented electrical steel and strip having excellent and stabilized magnetic characteristics in the rolling direction by continuous casting, comprising heating a continuous cast steel slab containing 0.005 – 0.060 percent of carbon, not more than 4.0 percent of silicon, 0.030 – 0.090 percent of manganese and 0.010 – 0.030 percent of sulfur to a temperature from 1250°C to 1350°C, hot rolling the slab continuously under the condition that the material is kept for 30 – 200 seconds in the temperature range between 1200°C and 950°C, and then cold rolling and annealing the sheet.

* * * * *

8

Table 2

<table>
<thead>
<tr>
<th>Slab No.</th>
<th>Temp. before the finish rolling (°C)</th>
<th>Holding period from 1200°C before the finish rolling sec.</th>
<th>Magnetic characteristics (W/kg)</th>
<th>Thickness of the final product (mm)</th>
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<tr>
<td></td>
<td></td>
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<td>Flux density Bₘ (Wb/m²)</td>
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<tr>
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<td>Invention</td>
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<td></td>
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<td>Comparison</td>
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<td>1.74</td>
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<td>8 1151</td>
<td>231 1.58</td>
<td>1.74</td>
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