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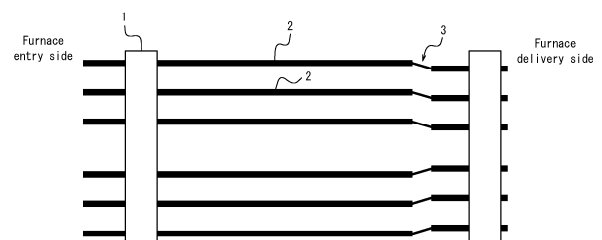
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(54) **HOT ROLLING METHOD, METHOD FOR PRODUCING GRAIN-ORIENTED ELECTROMAGNETIC STEEL SHEET, AND HOT-ROLLED COIL FOR GRAIN-ORIENTED ELECTROMAGNETIC STEEL SHEET**

(57) A method of hot rolling that can produce hot-rolled coils with few surface defects. A method of hot rolling in which a steel slab (1) is heated in a heating furnace and then hot-rolled. In a temperature range (T) in which a temperature of the steel slab (1) in the heating furnace is 950 °C or higher and 1150 °C or lower, when heating the steel slab (1) having a chemical composition in which a  $\gamma$  phase ratio is 20 mol% or less at 1050 °C, which is the median value of the temperature range (T), a distance between skids (2) supporting the steel slab (1) in the heating furnace is more than 1.1 m, and an average oxygen concentration in the heating furnace in the temperature range (T) is 5.0 vol% or less.

*FIG. 1*



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## Description

### TECHNICAL FIELD

5 **[0001]** The present disclosure relates to a method of hot rolling, a method of producing a grain-oriented electrical steel sheet, and a hot-rolled coil for a grain-oriented electrical steel sheet.

### BACKGROUND

10 **[0002]** Grain-oriented electrical steel sheets are produced by using precipitates, commonly called inhibitors, to induce secondary recrystallization of Goss-orientation ( $\{110\}\langle 001 \rangle$ ) grains during final annealing. For example, in Patent Literature (PTL) 1, a method using AlN as an inhibitor is described, and in PTL 2, a method using MnS, MnSe as an inhibitor is described, both of which have been put into industrial use.

15 **[0003]** Methods using the inhibitors above are useful methods for stably developing secondary recrystallized grains, but the precipitates must be finely dispersed. Therefore, it is necessary to heat a steel slab for a grain-oriented electrical steel sheet (hereinafter also referred to simply as "steel slab") to a high temperature of 1300 °C or higher before hot rolling.

**[0004]** However, high temperature heating of steel slabs not only increases apparatus costs, but also increases the amount of scale generated during hot rolling, thereby reducing yield and making apparatus maintenance more complicated.

20 **[0005]** On the other hand, a production technique that does not use the inhibitors mentioned above (inhibitorless method) has also been proposed. In PTL 3, a technique is described in which a steel slab of higher purity, containing no inhibitor components, is used as the steel slab, and secondary recrystallization is caused by texture (control of texture).

### CITATION LIST

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#### **[0006]**

PTL 1: JP S40-15644 B1

PTL 2: JP S51-13469 B2

30 PTL 3: JP 2000-129356 A

### SUMMARY

#### (Technical Problem)

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**[0007]** Steel slabs containing almost no inhibitor-forming elements do not need to be heated at temperatures exceeding 1300 °C, and therefore there is no need to use a special furnace when heating such steel slabs. Therefore, hot rolling can be carried out using slab heating apparatus such as a gas furnace that is used in typical steel production, making it possible to produce grain-oriented electrical steel sheets at low cost.

40 **[0008]** However, in some products, surface defects occur at specific positions on a hot-rolled coil obtained after hot rolling (hereinafter also referred to as a "hot-rolled coil"). As a result, this has had an effect on meandering of hot-rolled coils in a subsequent annealing process of a hot-rolled sheet and on fracture of the sheet in a cold rolling process, and has been one factor hindering industrial-scale production.

45 **[0009]** The present disclosure is made in view of the above problems, and it would be helpful to provide a method of hot rolling that can obtain a hot-rolled coil having fewer surface defects.

#### (Solution to Problem)

50 **[0010]** The inventors conducted a detailed investigation into the characteristics of defect occurrence in hot-rolled coils in which surface defects actually occurred, and came to the following discoveries.

1) Locations where surface defects occur roughly coincide with locations of skids that supported the steel slab when the steel slab was heated, where the material temperature is thought to be around 1050 °C (that is, the locations on the steel slab where the skids were in contact).

55 2) A  $\gamma$  phase ratio of a steel slab at around 1050 °C is approximately 20 mol% or less.

3) Regarding the air-fuel ratio (the ratio of the mass of air to the mass of fuel gas) during heating, the defect occurrence rate is high when the ratio of the mass of air is high.

**[0011]** The  $\gamma$  phase ratio in 2) above was calculated using thermodynamic software Thermo-calc ver.2019b (database TCFE7) by Thermo-Calc Software AB.

**[0012]** FIG. 1 is a schematic diagram of an example of a walking beam-type slab heating furnace (hereinafter also referred to simply as a "heating furnace"). In a walking beam-type heating furnace, a steel slab 1 is typically supported and transported by skids 2 extending approximately parallel to one another. Typically, the skids 2 are an alternating arrangement of fixed skids and movable skids, and the movable skids move up and down to lift and gradually transport the steel slab 1 from the furnace entry side to the furnace delivery side.

**[0013]** In the above structure, when the positions of the skids 2 used to support and transport the steel slab 1 are always the same relative to the steel slab 1 (that is, when the same skid 2 continues to support the same position on the underside of the steel slab 1), the underside of the steel slab 1 directly above the skids 2 is more difficult to heat. For this reason, one or more mechanisms called shift skids 3 are often installed inside the heating furnace, and the positions of the skids 2 supporting the steel slab 1 are changed after the shift skids 3.

**[0014]** The inventors checked corresponding positions in the steel slab 1 where surface defects occurred in the hot-rolled coil, taking into consideration the length of the steel slab 1 before rolling. As a result, while the steel slab 1 was in the heating furnace, the temperature of the steel slab 1 was around 1050 °C at positions that largely coincided with the positions of the skids 2 that were supporting the steel slab 1 (that is, the positions where the underside of the steel slab 1 was in contact with the skids 2). However, the steel slab 1 actually meandered slightly during transport within the heating furnace, resulting in an error (deviation) of 0.15 m from the corresponding positions on the steel slab 1.

**[0015]** Creep deformation occurring at high temperatures is more likely to occur in the  $\alpha$  (ferrite) phase and slower in the  $\gamma$  (austenite) phase, but since the frequency of occurrence varies depending on the  $\gamma$  phase ratio of the steel slab 1, creep behavior may be one factor. Further, the occurrence rate differs depending on the air-fuel ratio during heating, and therefore there is a possibility that the atmosphere, particularly the oxygen concentration, may have an effect.

**[0016]** Therefore, the inventors conducted the following laboratory experiment. First, the steel slab 1 was cast, containing, in mass%, C: 0.04 %, Si: 3.0 %, Mn: 0.10 %, Al: 0.007 %, and N, O, and S + 0.405  $\times$  Se each suppressed to less than 0.0060 %, with the balance being Fe and inevitable impurity. Next, a test piece measuring 4 mm square and 40 mm long was taken from the surface of the steel slab 1 after casting, and a creep test was carried out by applying stress to the test piece to bend at three points while being soaked at a temperature of 900 °C or higher and 1200 °C or lower in a heating furnace. At this time, the oxygen concentration in the heating furnace was changed from 0 vol% (100 vol% N<sub>2</sub>) to 20 vol% (80 vol% N<sub>2</sub>). As a result, it became clear that under conditions of high oxygen concentration and in a specific temperature range, deformation of the test piece did not stop there, but progressed to cracking.

**[0017]** Based on the discoveries obtained as described above, the inventors have hypothesized a mechanism by which surface defects are formed as follows. When the oxygen concentration is high at the surface of the steel slab 1 where tensile stress occurs directly above the skids 2, grain boundary embrittlement occurs due to oxidation, which progresses to cracking during hot working. However, for the skids 2 where the distance between two adjacent skids 2 is small, the stress exerted by each skid 2 on the steel slab 1 is small and deformation is suppressed, and therefore cracks do not develop.

**[0018]** Further, grain boundary embrittlement is promoted by grain boundary creep, and is therefore more likely to occur in  $\alpha$  (ferrite) single-phase steel, which is prone to creep as the steel slab 1, and the higher the  $\gamma$  (austenite) phase ratio, the less likely cracking is. Generally, when only creep deformation is considered, the higher the temperature, the greater the amount and rate of deformation. However, one of the causes of this phenomenon is the grain boundary segregation of elements contained as impurities, and at high temperatures these impurity elements become homogenized and no longer segregate, and therefore cracks develop only in a specific temperature range.

**[0019]** Based on the hypothesized mechanism, the inventors studied ways to decrease surface defects on hot-rolled coils. Electrical steel sheets contain a high concentration of Si in order to improve final magnetic properties. Si stabilizes the  $\alpha$  phase and decreases the  $\gamma$  phase ratio when heated at high temperatures. Further, C is an element that has a large effect on the  $\gamma$  phase ratio, but C has an effect of improving the hot-rolled microstructure and the texture during primary recrystallization, and therefore there is an appropriate amount of C from the viewpoint of improving the final magnetic properties. Accordingly, it is difficult to adopt a method of increasing the  $\gamma$  phase ratio at a given temperature by greatly changing the composition of electrical steel sheets that are already being produced by established processes.

**[0020]** Further, the temperature of the steel slab 1 gradually increases in the heating furnace, and therefore even when shortening the residence time in a specific temperature range is possible, completely avoiding the specific temperature range is difficult. Further, the steel slab 1 is supported by the skids 2, and therefore preventing stress from being applied to the steel slab 1 is difficult. The inventors then came up with a method of appropriately controlling the oxygen concentration in a heating furnace in a specific temperature range, and completed the present disclosure.

**[0021]** In order to solve the technical problems described above, the following are provided:

[1] A method of hot rolling comprising heating a steel slab in a heating furnace and then hot rolling, wherein,

in a temperature range T in which a temperature of the steel slab in the heating furnace is 950 °C or higher and

1150 °C or lower,  
when heating the steel slab having a chemical composition in which a  $\gamma$  phase ratio is 20 mol% or less at 1050 °C,  
which is the median value of the temperature range T, and when using the heating furnace in which a distance  
between skids supporting the steel slab exceeds 1.1 m,  
an average oxygen concentration in the heating furnace in the temperature range T is 5.0 vol% or less.

[2] The method of hot rolling according to [1], wherein the average oxygen concentration in the heating furnace in the temperature range T is 3.0 vol% or less.

[3] The method of hot rolling according to [1] or [2], wherein the hot rolling includes two consecutive passes of hot rolling, each pass being carried out in a temperature range from 1030 °C to 1150 °C, under conditions of a rolling reduction of 50 % or lower and a strain rate of 15/s or more, and a time between the two consecutive passes is 15 s or longer.

[4] A method of producing a grain-oriented electrical steel sheet, the method comprising: hot rolling a steel slab by the method of hot rolling according to any one of [1] to [3]; hot-rolled sheet annealing an obtained hot-rolled coil; then cold rolling once or cold rolling twice or more with intermediate annealing; then optionally carrying out decarburization annealing; and then carrying out final annealing to obtain a grain-oriented electrical steel sheet.

[5] A hot-rolled coil for a grain-oriented electrical steel sheet, the hot-rolled coil obtained by hot rolling a steel slab by the method of hot rolling according to any one of [1] to [3], wherein a number of surface defects in a range of  $L_0$  m before and after a rolling direction of the hot rolling with respect to a location corresponding to a position on a skid when the steel slab was heated is on average 0.3 or less,

where  $L_0$  m is derived from the following expression (1) where X is a width of the skid,  $Y_1$  m is a thickness of the steel slab, and  $Y_2$  m is a thickness of the hot-rolled coil for a grain-oriented electrical steel sheet,

$$L_0 \text{ m} = \{0.15 \text{ m} + X \text{ m}\} \times Y_1 \text{ mm} / Y_2 \text{ mm} \quad (1).$$

(Advantageous Effect)

**[0022]** According to the present disclosure, a hot-rolled coil with few surface defects is obtainable.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0023]** In the accompanying drawings:

FIG. 1 is a schematic diagram of an example of a walking beam-type slab heating furnace; and  
FIG. 2 is a diagram illustrating details of skids in a heating furnace used in tested examples.

## DETAILED DESCRIPTION

(Method of hot rolling)

**[0024]** The following describes embodiments of the present disclosure. The following description exemplifies embodiments of the present disclosure, and the present disclosure is not limited to the following embodiments in any way. The method of hot rolling according to the present disclosure is a method of hot rolling in which a steel slab is heated in a heating furnace and then hot-rolled. Here, in a temperature range T in which a temperature of the steel slab in the heating furnace is 950 °C or higher and 1150 °C or lower, when heating the steel slab having a chemical composition in which the  $\gamma$  phase ratio is 20 mol% or less at 1050 °C, which is the median value of the temperature range T, and when using the heating furnace in which a distance between skids supporting the steel slab exceeds 1.1 m, an average oxygen concentration in the heating furnace in the temperature range T is 5.0 vol% or less.

[Steel slab]

**[0025]** According to the present disclosure, the steel slab 1 for a grain-oriented electrical steel sheet is used as a starting material. First, a preferred chemical composition of the steel slab 1 is explained. In the following explanation of the chemical composition, "%" represents "mass%" and "ppm" represents "mass ppm" unless otherwise specified.

**[0026]** The steel slab 1 preferably has a chemical composition containing C, Si, and Mn in the ranges described below, with the balance being Fe and inevitable impurity.

C: 0.03 % or more and 0.08 % or less

**[0027]** When the C content exceeds 0.08 %, decreasing the C amount in the steel to 50 ppm or less, at which magnetic aging does not occur, becomes difficult, even when decarburization annealing is carried out. The C content is therefore preferably 0.08 % or less. Further, according to the present disclosure, sulfides and selenides present in a central layer of the steel slab 1 are preferably decreased to a size smaller than that which would cause problems during cold rolling by carrying out hot rolling twice under appropriate conditions in a specific temperature range (from 1030 °C to 1150 °C). In ordinary Si steels, the temperature range in hot rolling is such that a almost entirely ferrite single phase is formed. However, a target temperature coincides with a temperature range in which austenite phase is formed, albeit at a small volume fraction, suggesting that this contributes to the fragmentation and breaking up of sulfides and selenides. In practice, in steel having a C content of 0.02 %, the effect of fragmenting and breaking up sulfides and selenides cannot be obtained. The C content is therefore preferably 0.03 % or more.

Si: 2.0 % or more and 8.0 % or less

**[0028]** Si is a useful element that decreases iron loss by increasing electrical resistance. In order to obtain good magnetic properties, Si content is preferably 2.0 % or more. In order to obtain better magnetic properties, the Si content is more preferably 2.8 % or more. On the other hand, Si is also an element that increases the brittleness of steel, and when the Si content exceeds 8.0 %, the risk of breakage during sheet passing increases, and cold rolling properties also deteriorate significantly. The Si content is therefore preferably 8.0 % or less. In order to further decrease the risk during passing, the Si content is more preferably 4.5 % or less.

Mn: 0.005 % or more and 3.0 % or less

**[0029]** Mn is an element that has an effect of improving hot workability during production. When Mn content is less than 0.005 %, the effect is poor in terms of both improving hot workability and controlling oxide coating formation. The Mn content is therefore preferably 0.005 % or more. On the other hand, when the Mn content exceeds 3.0 %, the primary recrystallized texture degrades, resulting in degradation of the magnetic properties. The Mn content is therefore preferably 3.0 % or less. The Mn content is more preferably 0.010 % or more. The Mn content is more preferably 0.5 % or less.

**[0030]** According to the present disclosure, it is preferable to decrease the content of Al, N, S, and Se, which are components that form inhibitors, as much as possible. In this case, secondary recrystallization in the Goss orientation can be achieved by the texture inhibition effect. Therefore, it is preferable to decrease the content of Al, N, S, and Se in the chemical composition of the steel slab to the following ranges.

Al: less than 0.010 %

**[0031]** When the Al content is 0.010 % or more, it becomes difficult to obtain a secondary recrystallized microstructure due to the action of texture inhibition. The Al content is therefore preferably less than 0.010 %. On the other hand, from the viewpoint of the texture inhibition effect, the lower the Al content, the better, and the Al content may be 0 %.

O: 0.006 % or less

**[0032]** O also forms oxides, which degrade the magnetic properties of the steel sheet as a finished product. Accordingly, O content is preferably 0.006 % or less. The O content is more preferably 0.003 % or less. On the other hand, from the viewpoint of the texture inhibition effect, the lower the O content, the better, and the O content may be 0 %.

N: 0.006 % or less

**[0033]** N forms Si nitrides after purification annealing. In order to prevent the formation of the silicon nitrides, the N content is preferably 0.006 % or less. On the other hand, from the viewpoint of the texture inhibition effect, the lower the N content, the better, and the N content may be 0 %.

$S + 0.405 \times Se$ : 0.0060 % or less

**[0034]** In order to stably realize secondary recrystallization,  $S + 0.405 \times Se$  is preferably 0.0060 % or less. On the other hand, from the viewpoint of the texture inhibition effect, the lower  $S + 0.405 \times Se$  is, the better, and it may be 0 %, but excessive decrease leads to an increase in production costs. Therefore,  $S + 0.405 \times Se$  is preferably 0.0010 % or more.

**[0035]** \_Further, aside from the above elements, the present disclosure also includes one or more elements selected

from the group consisting of:

Ni: 0.005 % or more and 1.50 % or less,  
 Sn: 0.01 % or more and 0.50 % or less,  
 Sb: 0.005 % or more and 0.50 % or less,  
 Cu: 0.01 % or more and 0.50 % or less,  
 Mo: 0.01 % or more and 0.50 % or less,  
 P: 0.0050 % or more and 0.50 % or less,  
 Cr: 0.01 % or more and 1.50 % or less,  
 B: 0.0005 % or more and 0.0200 % or less,  
 Bi: 0.0005 % or more and 0.0200 % or less,  
 Nb: 0.0005 % or more and 0.0200 % or less,  
 Ti: 0.0005 % or more and 0.0200 % or less, and  
 Te: 0.0005 % or more and 0.0200 % or less.

Ni: 0.005 % or more and 1.50 % or less

**[0036]** Ni is a useful element in terms of improving the hot-rolled sheet microstructure for better magnetic properties. However, when Ni content is less than 0.005 %, the effect of improving the magnetic properties is small. The Ni content is therefore preferably 0.005 % or more. On the other hand, when the Ni content exceeds 1.50 %, the secondary recrystallization becomes unstable, and the magnetic properties degrade. Accordingly, the Ni content is preferably 1.50 % or less.

Sn: 0.01 % or more and 0.50 % or less  
 Sb: 0.005 % or more and 0.50 % or less  
 Cu: 0.01 % or more and 0.50 % or less  
 Mo: 0.01 % or more and 0.50 % or less  
 P: 0.0050 % or more and 0.50 % or less  
 Cr: 0.01 % or more and 1.50 % or less  
 B: 0.0005 % or more and 0.0200 % or less  
 Bi: 0.0005 % or more and 0.0200 % or less

**[0037]** The magnetic properties can be further improved by using grain boundary segregation elements such as Sn, Sb, Cu, Mo, P, Cr, B, and Bi. When the content of an element listed above is below the lower limit of the range listed, the effect of improving the magnetic properties is small, whereas when the content exceeds the upper limit, the development of secondary recrystallized grains is suppressed. Therefore, the content of each of Sn, Sb, Cu, Mo, P, Cr, B, and Bi is preferably in a range listed above.

Nb: 0.0005 % or more and 0.0200 % or less  
 Ti: 0.0005 % or more and 0.0200 % or less  
 Te: 0.0005 % or more and 0.0200 % or less

**[0038]** Nb, Ti, and Te are precipitate-forming elements. In production methods that do not use an inhibitor, these are not necessarily required, but adding a trace amount in a range in which a solid solution is formed by slab heating at a relatively low temperature may improve the magnetic properties. Therefore, the content of each of Nb, Ti, and Te is preferably the lower limit value listed above or more. On the other hand, when the content of any of Nb, Ti, and Te exceeds the upper limit value listed above, the secondary recrystallization becomes unstable. Therefore, the content of each of Nb, Ti, and Te is preferably the upper limit value listed above or less.

**[0039]** The molten steel adjusted to the preferred chemical composition is refined by a known method using a converter, an electric furnace, or the like, and when required, subjected to vacuum treatment or the like, and then the steel slab 1 is produced by normal ingot casting or continuous casting. Alternatively, a thin slab or thinner cast steel having a thickness of 100 mm or less may be directly produced by direct casting.

**[0040]** Next, the steel slab 1 having the chemical composition listed above is hot-rolled to form a hot-rolled sheet. The steel slab 1 can be heated in a heating furnace to a temperature of, for example, 1050 °C or higher and lower than 1300 °C, and then hot rolled. The steel slab 1 of the present disclosure, preferably when inhibitor components are suppressed, has no need to be subjected to high temperature treatment at 1300 °C or higher for complete solid solution of precipitates, in particular. When the steel slab 1 is heated to a temperature of 1300 °C or higher, the crystal microstructure becomes too large, making control of the texture difficult. Therefore, the maximum temperature during heating is preferably less than

1300 °C. On the other hand, in order to smoothly roll the steel slab 1, the steel slab 1 is preferably heated to a temperature of 1050 °C or higher. Here, the temperature of the steel slab 1 is a surface temperature of the steel slab 1.

**[0041]** Here, the inventors calculated based on the chemical composition of the steel slab 1 that, when heating the steel slab 1 in the temperature range T in which the temperature of the steel slab 1 in the heating furnace is 950 °C or higher and 1150 °C or lower, and the  $\gamma$  phase fraction is 20 mol% or less at the median value of the temperature range T, 1050 °C, when the heating furnace is used in which a distance between the skids 2 supporting the steel slab 1 (hereinafter also referred to as "skid spacing") exceeds 1.1 m, it is essential that the average oxygen concentration in the heating furnace in the temperature range T be 5.0 vol% or less.

**[0042]** Even within the same heating furnace, the skid spacing is not necessarily equal. As a result of the investigation by the inventors, they focused on a specific skid 2 among the skids 2 and found that when the distance to two adjacent skids 2 exceeded 1.1 m on both sides, a defect occurred at a position on the hot-rolled coil corresponding to the contact position between the specific skid 2 and the steel slab 1. Therefore, focusing on a specific skid 2, when the distance to two adjacent skids 2 exceeds 1.1 m on both sides, the average oxygen concentration in the heating furnace is 5.0 vol% or less.

**[0043]** Here, "skid spacing" does not refer to the distance between the centers of two skids 2, but rather refers to the distance of the space (gap) between the centers of two skids 2. Here, the skid spacing is not taken into consideration for the skids 2 at both ends. The average oxygen concentration in the heating furnace means the time average of the oxygen concentration in the heating furnace. Further, when the heating temperature of the steel slab 1 is a temperature in the range from 950 °C to 1150 °C, such as 1050 °C, the average oxygen concentration in the heating furnace is 5.0 vol% or less in the temperature range from 950 °C to 1050 °C.

**[0044]** From the viewpoint of suppressing hot cracking, the lower the oxygen concentration in the heating furnace, the better. However, in the case of a heating furnace that uses a mixture of air and fuel gas, or a heating furnace in which air may be drawn into the heating furnace when the steel slab 1 is charged or discharged, an inhibitory effect on the formation of surface defects can be greatly exerted by the average oxygen concentration being 5.0 vol% or less. The average oxygen concentration is more preferably 3.0 vol% or less, as this can further enhance the inhibitory effect on the formation of surface defects. The average oxygen concentration is even more preferably 0.5 vol% or less, as this can almost completely prevent the formation of surface defects.

**[0045]** The temperature range T from 950 °C to 1150 °C often corresponds to the middle of the heating process in slab heating. Therefore, in the temperature range T, it is rare to directly measure the temperature of the steel slab 1 or continuously sample the atmospheric gas at a target location in the heating furnace to measure the oxygen concentration. On the other hand, the atmosphere inside the furnace changes from moment to moment, as the air-fuel ratio changes when the temperature inside the furnace is changed, and air is drawn in when the steel slab 1 is charged or discharged. Therefore, in order to control the oxygen concentration as described above, it is preferable to measure the slab temperature directly or to ascertain the target temperature range by calculation. In order to continuously ascertain the gas atmosphere in the target temperature range, it is preferable to use a heating furnace having a mechanism that continuously measures the atmosphere at at least one location in the heating furnace and increases the amount of inert gas introduced to decrease the oxygen concentration in response to fluctuations in the atmosphere.

**[0046]** The steel slab 1 is subsequently subjected to hot rolling, and in order to improve the shape of the hot-rolled coil and prevent minor surface defects from becoming apparent, the following rolling conditions are preferably applied. That is, it is preferable that at least two consecutive rolling passes from the stage of the steel slab 1 to the stage of a sheet bar be carried out in the temperature range from 1030 °C to 1150 °C, with each pass having a rolling reduction of 50 % or less, a strain rate of 15/s or more, and the time between the two passes being 5 s or longer. The time between the two passes is more preferably 15 s or longer.

**[0047]** When the steel slab 1 is used that contains 0.03 % or more of C in the chemical composition and has a  $\gamma$  phase ratio of 20 mol% or less at temperatures of 950 °C or higher and 1150 °C or lower in the heating furnace, the  $\gamma$  phase ratio is at maximum at a temperature in the vicinity of 1030 °C or higher and 1150 °C or lower. In general, the austenite phase has a higher deformation resistance than the ferrite phase, and is less likely to deform even when rolled. Therefore, the rolling reduction in each pass is preferably limited to 50 % or less. When the rolling reduction is too great, even minor surface defects before rolling will be greatly enlarged by friction with the rollers, and will become more likely to become apparent. Further, by setting the time between the two passes to 15 s or longer, dislocations formed once by deformation are recovered or eliminated by recrystallization, and therefore rolling can be carried out without excessively increasing deformation resistance. This also works to the advantage in terms of suppressing friction. Further, the strain rate is preferably 15/s or more. When the strain rate is low, that is, the rolling speed is slow, the temperature gradually decreases from the roll bite until the end of rolling, making it difficult to carry out rolling properly and potentially leading to shape deterioration.

**[0048]** The strain rate was calculated using the following Ekelund expression (2).  
[Math. 1]

$$\frac{d\varepsilon}{dt} \doteq \frac{v_R}{\sqrt{R'h_1}} \frac{2}{2-r} \times \sqrt{r} \quad (2)$$

**[0049]** Here,  $d\varepsilon/dt$  is the strain rate per second,  $v_R$  is the roller peripheral speed in mm/s,  $R'$  is the roll radius in mm,  $h_1$  is the roller entry side thickness in mm, and  $r$  is the rolling reduction %. By applying such a rolling schedule, it is possible to improve the shape of the hot-rolled coil while suppressing the appearance of minor surface defects.

**[0050]** The presence or absence of surface defects in the hot-rolled coil can be evaluated visually. Further, by subjecting the hot-rolled coil to a treatment that makes surface defects more apparent, whether or not there are surface defects can be evaluated more easily. For example, a sample is cut from a portion of the hot-rolled coil corresponding to a position of a skid 2 supporting the steel slab 1 in the heating furnace, and then the sample is pickled to remove surface scale, dried at 180 °C for one minute, and then left to stand for several days. This causes localized rusting at locations where defects exist, making it easier to evaluate whether or not there are surface defects.

**[0051]** However, in actual operation, cutting from the hot-rolled coil leads to a significant deterioration in yield, so it is preferable to use a defect detector using a typical defect evaluation device such as an eddy current sensor or an optical camera.

**[0052]** Here, a method is described of determining a position on the hot-rolled coil corresponding to a position of the skids 2 supporting the steel slab 1 in the heating furnace (that is, a contact position between the steel slab 1 and the skids 2). For example, when rolling the steel slab 1 having a thickness of 200 mm to 2 mm, there is a skid 2 of interest (that is, the skid spacing is more than 1.1 m) located 3 m from the rolling direction end of the steel slab 1, and the width of the skid 2 itself supporting the steel slab 1 is 50 mm. In this case, a position 3 m from the rolling direction end of the steel slab 1 corresponds to a position  $3 \text{ m} \times (200 \text{ mm} / 2 \text{ mm}) = 300 \text{ m}$  from the rolling direction end of the hot-rolled coil. Further, the width of the skid 2 in contact with the steel slab 1 is 50 mm, but the 50 mm wide region in the steel slab 1, due to the above-mentioned 0.15 m error margin and the 50 mm width of the skid 2, expands to a  $(50 \text{ mm} + 0.15 \text{ m} \times 2) \times (200 \text{ mm} / 2 \text{ mm}) = 35 \text{ m}$  wide region in the hot-rolled coil. Therefore, the region of 17.5 m before and after the position 300 m from the rolling direction end of the hot-rolled coil corresponds to the position 3 m from the rolling direction end of the steel slab 1.

**[0053]** However, when the width of the steel slab 1 increases due to rolling (for example, when the steel slab 1 having a width of 1 m becomes 1.1 m wide), the amount of elongation in the rolling direction is decreased to take into account the increase in width. In the above example, the region 17.5 m before and after the center position 300 m from the end is the target of surface defect evaluation, and the number of surface defects within this region is evaluated. By using the method of the present disclosure, it is possible to suppress the occurrence of surface defects in hot-rolled coils. When the number of surface defects is added up for a plurality of hot-rolled coils or for a plurality of target skids for a single hot-rolled coil and averaged as the number of defects occurring per skid (for example, for 20 or more coils), the number can be decreased to 0.3 or less.

**[0054]** In the above explanation, the evaluation method for hot-rolled coils has been described. However, even in the case of coils after cold rolling, which is carried out later, surface defects can be evaluated by setting similar target locations and using similar methods, although the target sheet thickness is different.

(Method of producing a grain-oriented electrical steel sheet)

**[0055]** The following describes a method of producing a grain-oriented electrical steel sheet according to the present disclosure. The method of producing a grain-oriented electrical steel sheet according to the present disclosure includes: hot rolling the steel slab 1 by the method of hot rolling according to the present disclosure; hot-rolled sheet annealing an obtained hot-rolled coil; then cold rolling once or cold rolling twice or more with intermediate annealing; then optionally carrying out decarburization annealing; and then carrying out final annealing to obtain a grain-oriented electrical steel sheet.

**[0056]** After the hot rolling, hot-rolled sheet annealing and cold rolling are carried out. In the hot-rolled coil in which surface defects are suppressed, breakage during the cold rolling process can be suppressed.

**[0057]** The hot-rolled sheet annealing is preferably at 1150 °C or lower. When the temperature of the hot-rolled sheet annealing exceeds 1150 °C, inhibitor-forming components that are inevitably mixed in form a solid solution and are unevenly reprecipitated during cooling, making it difficult to achieve a uniformly-sized grain for the primary recrystallized texture and inhibiting the development of secondary recrystallization. Further, when the temperature of the hot-rolled sheet annealing exceeds 1150 °C, the grain size after the hot-rolled sheet annealing becomes too coarse, which is also disadvantageous in realizing an appropriate primary recrystallized texture. Therefore, the hot-rolled sheet annealing is preferably at 1150 °C or lower.

**[0058]** After the hot-rolled sheet annealing, the sheet is subjected to cold rolling once or more with intermediate annealing as required, and then decarburization annealing is carried out to decrease the C content to 50 ppm or less, at which magnetic aging does not occur, and preferably 30 ppm or less.

**[0059]** In cold rolling, it is effective in terms of developing a Goss texture to carry out aging treatment once or more times at a rolling temperature of 80 °C or higher and 150 °C or lower, and at an inter-pass temperature of 100 °C or higher and 300 °C or lower.

**[0060]** Further, the decarburization annealing after the final cold rolling is intended to decarburize and to cause primary recrystallization of the cold rolled sheet having a rolled microstructure, to adjust the primary recrystallized grain size to an optimum size for secondary recrystallization. For this reason, decarburization annealing is carried out in a H<sub>2</sub> mixed atmosphere at a controlled dew point of 750 °C or higher and 900 °C or lower. When the temperature is increased during annealing, when the heating rate from 550 °C to 680 °C is 200 °C/s or more, the texture improving effect can be further enhanced. Further, after decarburization annealing, a technique for increasing the Si content by siliconizing or a technique for increasing the N content by nitriding may be used in combination.

**[0061]** Thereafter, final annealing is carried out to develop a secondary recrystallized microstructure. At this time, a forsterite film may be formed using an annealing separator containing MgO as the main component. The formation of the forsterite film can be further favored by adding an appropriate amount of Ti oxide, Sr compound, or the like to the separator. In particular, the addition of auxiliaries that promote uniform forsterite film formation is also advantageous for improving peeling properties. Further, any annealing separator such as Al<sub>2</sub>O<sub>3</sub> may be used to inhibit film formation.

**[0062]** The final annealing is preferably carried out at 800 °C or higher to induce secondary recrystallization, but the heating rate up to 800 °C does not have a large effect on the magnetic properties, and therefore can be carried out under any conditions. The annealing atmosphere can be any of N<sub>2</sub>, Ar, H<sub>2</sub>, or a mixture thereof. To more effectively carry out secondary recrystallization, the temperature can be maintained isothermally near the secondary recrystallization temperature. However, maintaining isothermally is not necessarily required, as a slow heating rate is also effective. Precipitation of trace components in the final product leads to degradation of magnetic properties, and therefore, for component purification, the maximum temperature of annealing is preferably 1100 °C or higher.

**[0063]** After the final annealing, an insulating coating may be further applied to the steel sheet surface and baked. Such an insulating coating is not limited to a particular type, and any conventionally known insulating coating is applicable. For example, a preferred method is described in JP S50-79442 A and JP S48-39338 A, where a coating solution containing phosphate-chromate-colloidal silica is applied on a steel sheet and then baked at a temperature of around 800 °C.

**[0064]** Further, flattening annealing may be carried out to correct the shape of the steel sheet. This flattening annealing may also serve as an insulating coating baking treatment.

(Hot-rolled coil for grain-oriented electrical steel sheet)

**[0065]** The hot-rolled coil for a grain-oriented electrical steel sheet according to the present disclosure is a hot-rolled coil obtained by hot rolling the steel slab 1 by the method of hot rolling according to the present disclosure, wherein a number of surface defects in a range of L<sub>0</sub> m before and after the rolling direction of the hot rolling with respect to a location corresponding to a position on the skids 2 when the steel slab 1 was heated is on average 0.3 or less. Here, L<sub>0</sub> m is derived from the following expression (1) where X is a width of the skid 2, Y<sub>1</sub> m is a thickness of the steel slab 1, and Y<sub>2</sub> m is a thickness of the hot-rolled coil for a grain-oriented electrical steel sheet.

$$L_0 \text{ m} = \{0.15 \text{ m} + X \text{ m}\} \times Y_1 \text{ mm} / Y_2 \text{ mm} \quad (1)$$

**[0066]** As described above, in the method of hot rolling according to the present disclosure, in the temperature range T in which the temperature of the steel slab 1 in the heating furnace is 950 °C or higher and 1150 °C or lower, the average oxygen concentration in the heating furnace in the temperature range T is 5.0 vol% or less. This decreases surface defects at positions on the hot-rolled coil that correspond to positions on the steel slab 1 supported by the target skid 2. Specifically, the region L<sub>0</sub> m before and after the position X m × Y<sub>1</sub> mm/Y<sub>2</sub> mm from the end of the hot-rolled coil corresponds to the position where the steel slab 1 is supported by the target skid 2, and the occurrence of surface defects in the above region can be suppressed to an average of 0.3 or less. The average number of surface defects may be, for example, an average over 20 or more coils.

## EXAMPLES

(Example 1)

**[0067]** The steel slab 1 having a thickness of 200 mm and containing no inhibitor components, containing, in mass%, C:

0.035 % or more and 0.055 % or less, Si: 3.0 % or more and 3.4 % or less, Mn: 0.07 %, Al: 0.005 % or more and 0.008 % or less, and N, O, S + 0.405 × Se: each less than 0.0060 %, with the balance being Fe and inevitable impurity, was heated in a heating furnace including the skids 2 that have a skid width of 50 mm and skid spacing as illustrated in FIG. 2. The sums of the numerical values in FIG. 2 indicate the distances from the center of skid D or the center of skid C to the rolling direction end of the steel slab 1.

**[0068]** In the heating furnace, either of the following heating patterns was adopted: pattern A, in which the steel slab 1 was heated to 1150 °C upstream of a shift skid 3 (hereinafter also referred to as "before shift") and then heated to 1250 °C downstream of the shift skid 3 (hereinafter referred to as "after shift"), or pattern B, in which the steel slab 1 was heated to 950 °C before shift and then heated to 1200 °C after shift. Further, for the heating furnace, a heat-resistant gas suction tube was installed inside the heating furnace, and a mechanism for continuously measuring the oxygen concentration was provided. By controlling the amount of N<sub>2</sub> gas supplied to the positions before shift and after shift, fluctuations in the oxygen concentration when the heating furnace was opened or closed and when the burner combustion efficiency was changed were controlled in real time. Further, under certain conditions (No. 13 in Table 1), an experiment was also conducted in which the oxygen concentration inside the heating furnace momentarily increased due to the influence of air entering the heating furnace when the heating furnace was opened or closed. In Table 1, for No. 13, the values in parentheses for the average oxygen concentration in the furnace before shift and the average oxygen concentration in the furnace after shift indicate the values after the heating furnace was momentarily opened and closed. The temperature of the steel slab 1 was determined by heating the steel slab 1 with a thermocouple attached in the heating furnace, evaluating the heat input to the steel slab 1, and then calculating the temperature from the furnace temperature using numerical calculations. The experiment was conducted based on this calculated slab temperature. After being removed from the heating furnace, the third and fourth passes of a four-pass rough rolling process were carried out under the conditions listed in Table 1. Subsequently, finishing hot rolling was carried out in a temperature range from 850 °C to 950 °C in a plurality of passes to finish to a thickness of 2.0 mm. Further, in the finishing hot rolling, appropriate tension was applied to the steel sheet between the rollers to suppress width expansion as much as possible. 20 hot-rolled coils were produced under the same conditions.

**[0069]** From each obtained hot-rolled coil, a sample was cut out from a location corresponding to the position on the steel slab 1 supported by the target skid 2 (the contact position between the steel slab 1 and the target skid 2), using the rolling direction end as a reference point. For each sample, the sample was pickled in 5 % HCl at 80 °C for 120 s to remove surface scale, then surfaces were dried by heat treatment at 180 °C for 1 min, and left for 7 days, after which the number of locations where localized rust had occurred was counted. The results are listed in Table 2.

**[0070]** In Table 2, the skids 2 targeted by the present disclosure are those indicated by "c" before shift and "C and D" after shift, and the Comparative Examples had many surface defects, at 2.5 or more per skid. In contrast, according to Examples following the present disclosure, the number of surface defects was small, at 0.3 or less per skid, and when the oxygen concentration was 3.0 vol% or less, the number was 0.1 or less per skid, meaning that surface defects were almost completely prevented. As described above, it is clear that the present disclosure can significantly reduce the number of surface defects.

[Table 1]

[0071]

Table 1

| No | Added components (mass%) |     |      |       |       |           | 1050 °C<br>γ phase<br>ratio<br>(mol%) | Heating<br>pattern | Average<br>oxygen<br>concentration<br>in furnace<br>before shift<br>(vol%) | Average<br>oxygen<br>concentration<br>in furnace<br>after shift<br>(vol%) | Average<br>oxygen<br>concentratio<br>n in furnace<br>(vol%) | Rough rolling 3rd pass |                             |                        | Rough rolling 4th pass |                             |                        | Time<br>between<br>3rd and<br>4th pass<br>(s) |
|----|--------------------------|-----|------|-------|-------|-----------|---------------------------------------|--------------------|----------------------------------------------------------------------------|---------------------------------------------------------------------------|-------------------------------------------------------------|------------------------|-----------------------------|------------------------|------------------------|-----------------------------|------------------------|-----------------------------------------------|
|    | C                        | Si  | Mn   | Al    | N     | S+0.405Se |                                       |                    |                                                                            |                                                                           |                                                             | Temp.<br>(°C)          | Rolling<br>reduction<br>(%) | Strain<br>rate<br>(/s) | Temp.<br>(°C)          | Rolling<br>reduction<br>(%) | Strain<br>rate<br>(/s) |                                               |
| 1  |                          |     |      |       |       |           | 5                                     | A                  | <u>5.1</u>                                                                 | 3.5                                                                       | 4.5                                                         | 1035                   | 25                          | 25                     | 1010                   | 38                          | 40                     | 28                                            |
| 2  |                          |     |      |       |       |           |                                       |                    | 4.8                                                                        | 2.5                                                                       | 3.9                                                         | 1110                   | 30                          | 25                     | 1080                   | 30                          | 25                     | 45                                            |
| 3  | 0.035                    | 3.4 | 0.07 | 0.006 | 0.004 | 0.0012    |                                       |                    | 2.7                                                                        | 2.4                                                                       | 2.6                                                         | 1080                   | 55                          | 45                     | 1050                   | 30                          | 25                     | 43                                            |
| 4  |                          |     |      |       |       |           |                                       |                    | 2.6                                                                        | 2.5                                                                       | 2.6                                                         | 1080                   | 30                          | 25                     | 1050                   | 30                          | 28                     | 50                                            |
| 5  |                          |     |      |       |       |           |                                       |                    | 2.8                                                                        | 2.6                                                                       | 2.7                                                         | 1160                   | 31                          | 25                     | 1120                   | 42                          | 40                     | 38                                            |
| 6  |                          |     |      |       |       |           | 10                                    | B                  | 7.3                                                                        | 3.4                                                                       | 5.7                                                         | 1090                   | 28                          | 25                     | 1070                   | 18                          | 13                     | 90                                            |
| 7  |                          |     |      |       |       |           |                                       |                    | 7.3                                                                        | 3.4                                                                       | 5.7                                                         | 1090                   | 28                          | 25                     | 1070                   | 45                          | 40                     | 14                                            |
| 8  |                          |     |      |       |       |           |                                       |                    | 7.3                                                                        | 3.4                                                                       | 5.7                                                         | 1090                   | 28                          | 25                     | 1070                   | 18                          | 42                     | 30                                            |
| 9  | 0.040                    | 3.2 | 0.07 | 0.008 | 0.005 | 0.0038    |                                       |                    | 3.2                                                                        | <u>5.2</u>                                                                | 4.0                                                         | 1090                   | 28                          | 25                     | 1070                   | 18                          | 42                     | 14                                            |
| 10 |                          |     |      |       |       |           |                                       |                    | 6.2                                                                        | 2.2                                                                       | 4.6                                                         | 1070                   | 30                          | 25                     | 1050                   | 30                          | 25                     | 38                                            |
| 11 |                          |     |      |       |       |           |                                       |                    | 0.9                                                                        | 0.5                                                                       | 0.7                                                         | 1150                   | 52                          | 45                     | 1100                   | 25                          | 20                     | 55                                            |
| 12 |                          |     |      |       |       |           |                                       |                    | 0.9                                                                        | 0.5                                                                       | 0.7                                                         | 1150                   | 48                          | 50                     | 1100                   | 25                          | 20                     | 55                                            |
| 13 |                          |     |      |       |       |           |                                       |                    | <u>0.9 (4.2)</u>                                                           | <u>0.5 (5.4)</u>                                                          | <u>0.7 (4.7)</u>                                            | 1100                   | 35                          | 30                     | 1060                   | 35                          | 30                     | 20                                            |
| 14 |                          |     |      |       |       |           |                                       |                    | A                                                                          | 2.9                                                                       | 2.3                                                         | 1100                   | 18                          | 22                     | 1070                   | 55                          | 46                     | 13                                            |
| 15 | 0.055                    | 3.4 | 0.07 | 0.005 | 0.003 | 0.0024    |                                       |                    | B                                                                          | 0.9                                                                       | 2.5                                                         | 1100                   | 25                          | 25                     | 1070                   | 26                          | 21                     | 50                                            |

Note: underlining indicates a value outside the scope of the present disclosure.

[Table 2]

[0072]

Table 2

| No                                                                               | Number of surface defects (per skid) |     |     |     |            |            |            |     |     |   |     |     | Remarks             |
|----------------------------------------------------------------------------------|--------------------------------------|-----|-----|-----|------------|------------|------------|-----|-----|---|-----|-----|---------------------|
|                                                                                  | A                                    | a   | B   | b   | C          | c          | D          | d   | e   | E | f   | F   |                     |
| 1                                                                                | 0                                    | 0   | 0   | 0   | 0          | <u>5.6</u> | 0          | 0   | 0   | 0 | 0   | 0   | Comparative Example |
| 2                                                                                | 0                                    | 0.1 | 0   | 0   | 0          | 0.3        | 0          | 0   | 0   | 0 | 0.1 | 0   | Example             |
| 3                                                                                | 0                                    | 0   | 0   | 0   | 0          | 0.1        | 0          | 0   | 0.1 | 0 | 0   | 0   | Example             |
| 4                                                                                | 0                                    | 0   | 0   | 0.1 | 0          | 0          | 0          | 0   | 0   | 0 | 0   | 0   | Example             |
| 5                                                                                | 0                                    | 0.1 | 0   | 0   | 0          | 0.1        | 0          | 0   | 0   | 0 | 0   | 0   | Example             |
| 6                                                                                | 0                                    | 0.1 | 0   | 0   | 0.3        | 0          | 0.2        | 0   | 0   | 0 | 0.1 | 0   | Example             |
| 7                                                                                | 0                                    | 0   | 0.1 | 0   | 0.3        | 0          | 0.2        | 0   | 0   | 0 | 0   | 0   | Example             |
| 8                                                                                | 0                                    | 0   | 0.1 | 0   | 0.2        | 0          | 0.1        | 0   | 0   | 0 | 0   | 0   | Example             |
| 9                                                                                | 0                                    | 0   | 0.1 | 0   | <u>4.8</u> | 0          | <u>5.5</u> | 0   | 0   | 0 | 0   | 0   | Comparative Example |
| 10                                                                               | 0                                    | 0.1 | 0   | 0   | 0.1        | 0          | 0          | 0.1 | 0   | 0 | 0   | 0   | Example             |
| 11                                                                               | 0                                    | 0   | 0   | 0   | 0          | 0          | 0.1        | 0   | 0   | 0 | 0   | 0   | Example             |
| 12                                                                               | 0                                    | 0   | 0   | 0   | 0          | 0          | 0          | 0   | 0   | 0 | 0   | 0   | Example             |
| 13                                                                               | 0.1                                  | 0   | 0   | 0   | <u>3.1</u> | 0          | <u>2.5</u> | 0   | 0.1 | 0 | 0   | 0.1 | Comparative Example |
| 14                                                                               | 0                                    | 0   | 0   | 0   | 0          | 0.1        | 0          | 0   | 0   | 0 | 0   | 0   | Example             |
| 15                                                                               | 0                                    | 0   | 0   | 0   | 0          | 0          | 0          | 0   | 0   | 0 | 0   | 0   | Example             |
| Note: underlining indicates a value outside the scope of the present disclosure. |                                      |     |     |     |            |            |            |     |     |   |     |     |                     |

(Example 2)

**[0073]** The steel slab 1 containing C: 0.04 %, Si: 3.3 %, Mn: 0.05 %, and other components listed in Table 3, and having a calculated  $\gamma$  phase ratio of 20 mol% or less over the entire temperature range, was heated using the heating furnace having the skid arrangement illustrated in FIG. 2 in the same manner as in Example 1, with a heating pattern of heating to 1150 °C before shift and to 1250 °C after shift, and hot-rolled under the conditions listed in Table 3. 20 hot-rolled coils were produced under the same conditions, and for ten of the coils, a portion was cut out at a position corresponding to the position on the steel slab 1 where it was supported by the skid 2 marked as the reference sign "c". The amount of surface defects was evaluated in the same manner as in Example 1. The hot-rolled coils from which no samples were taken (ten coils) were subjected to hot-rolled sheet annealing at an end-point temperature of 1020 °C. Thereafter, each material was divided into two types: a two-pass rolling method in which the final sheet thickness was obtained by rolling twice, and a one-pass rolling method in which the final thickness was obtained by rolling once. For the two-pass rolling method material, a first cold rolling was carried out in a reverse mill at 100 °C to 1.7 mm, and after the target thickness was reached, intermediate annealing was carried out at 900 °C for 1 min, and then a second reverse cold rolling was carried out, with coiling aging treatment at 200 °C being carried out, thereby obtaining a sheet thickness of 0.22 mm. Further, the material allocated to the one-pass rolling method was rolled to a thickness of 0.26 mm using a tandem mill. It was also evaluated whether each material (ten coils) fractured during passing through the rolling line. The cold-rolled sheet having the final sheet thickness was subjected to primary recrystallization annealing with a heating rate of 300 °C/s from 550 °C to 680 °C, a soaking temperature of 840 °C, and a soaking time of 60 s, and then an annealing separator containing 95 % MgO and 5 % TiO<sub>2</sub> was applied to the steel sheet surface as an aqueous slurry, and the steel sheet was subjected to secondary recrystallization annealing. A coating solution containing phosphate-chromate-colloidal silica in a mass ratio of 3:1:3 was applied to the surface of the final annealed sheet obtained in this way, and baked at 800 °C. The magnetic properties of a widthwise center portion of the obtained product sheet coil were also confirmed. In Table 3, when "other components" are not included, when  $B_8$  (magnetic flux density at a magnetizing force of 800 A/m) is 1.910 or more, it can be determined that the magnetic properties are good. When "other components" are included, when  $B_8$  is 1.915 or more, it can be determined that the magnetic properties are good.

[Table 3]

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[0074]

Table 3

| No | Added components (mass%) |     |      |       |       |           | Average oxygen concentration before shift (vol%) | Production process | Rough rolling 3rd pass |                       |                  | Rough rolling 4th pass |                       |                  | Time between 3rd and 4th pass (s) | Number of surface defects at skid c position | Fracture rate during rolling (%) | Magnetic flux density B <sub>8</sub> (T) |
|----|--------------------------|-----|------|-------|-------|-----------|--------------------------------------------------|--------------------|------------------------|-----------------------|------------------|------------------------|-----------------------|------------------|-----------------------------------|----------------------------------------------|----------------------------------|------------------------------------------|
|    | C                        | Si  | Mn   | Al    | N     | S+0.405Se | Other components                                 |                    | Temp. (°C)             | Rolling reduction (%) | Strain rate (/s) | Temp. (°C)             | Rolling reduction (%) | Strain rate (/s) |                                   |                                              |                                  |                                          |
| 16 | 0.04                     | 3.3 | 0.05 | 0.007 | 0.004 | 0.0036    |                                                  | two-pass rolling   | 1170                   | 30                    | 25               | 1130                   | 35                    | 30               | 53                                | 6.5                                          | -                                | -                                        |
| 17 |                          |     |      | 0.007 | 0.004 | 0.0036    |                                                  | two-pass rolling   | 1170                   | 30                    | 25               | 1130                   | 35                    | 30               | 53                                | -                                            | 20                               | 1.902                                    |
| 18 |                          |     |      | 0.006 | 0.005 | 0.0038    |                                                  | two-pass rolling   | 1120                   | 55                    | 48               | 1090                   | 22                    | 20               | 35                                | 0.3                                          | -                                | -                                        |
| 19 |                          |     |      | 0.006 | 0.005 | 0.0038    |                                                  | two-pass rolling   | 1120                   | 55                    | 48               | 1090                   | 22                    | 20               | 35                                | -                                            | 0                                | 1.908                                    |
| 20 |                          |     |      | 0.006 | 0.005 | 0.0038    |                                                  | one-pass rolling   | 1120                   | 30                    | 25               | 1090                   | 35                    | 30               | 44                                | 0                                            | -                                | -                                        |
| 21 |                          |     |      | 0.006 | 0.005 | 0.0038    |                                                  | one-pass rolling   | 1120                   | 30                    | 25               | 1090                   | 35                    | 30               | 44                                | -                                            | 0                                | 1.912                                    |
| 22 |                          |     |      | 0.005 | 0.003 | 0.0033    | Ni:0.03, Sn:0.01, P:0.07                         | one-pass rolling   | 1090                   | 28                    | 25               | 1070                   | 18                    | 13               | 90                                | -                                            | 10                               | 1.916                                    |
| 23 |                          |     |      | 0.005 | 0.003 | 0.0033    | Ni:0.03, Sn:0.01, P:0.07                         | one-pass rolling   | 1120                   | 30                    | 25               | 1090                   | 35                    | 30               | 44                                | -                                            | 0                                | 1.922                                    |
| 24 |                          |     |      | 0.004 | 0.003 | 0.0030    | Sb:0.03, Mo:0.04, Cr:0.04                        | two-pass rolling   | 1095                   | 35                    | 32               | 1075                   | 33                    | 35               | 56                                | -                                            | 0                                | 1.921                                    |
| 25 |                          |     |      | 0.004 | 0.003 | 0.0030    | Sb:0.03, Mo:0.04, Cr:0.04                        | two-pass rolling   | 1160                   | 35                    | 32               | 1120                   | 33                    | 35               | 56                                | -                                            | 10                               | 1.900                                    |
| 26 | 0.04                     | 3.3 | 0.05 | 0.008 | 0.004 | 0.0029    | Cu:0.02, B:0.001                                 | two-pass rolling   | 1105                   | 29                    | 25               | 1065                   | 55                    | 51               | 18                                | -                                            | 10                               | 1.917                                    |
| 27 |                          |     |      | 0.008 | 0.004 | 0.0029    | Cu:0.02, B:0.001                                 | two-pass rolling   | 1105                   | 29                    | 30               | 1065                   | 40                    | 38               | 35                                | -                                            | 0                                | 1.921                                    |

(continued)

| No                                                                               | Added components (mass%) |    |    |       |       |           |                                     | Average oxygen concentration before shift (vol%) | Production process | Rough rolling 3rd pass |                       |                  | Rough rolling 4th pass |                       |                  | Time between 3rd and 4th pass (s) | Number of surface defects at skid c position | Fracture rate during rolling (%) | Magnetic flux density B <sub>8</sub> (T) |
|----------------------------------------------------------------------------------|--------------------------|----|----|-------|-------|-----------|-------------------------------------|--------------------------------------------------|--------------------|------------------------|-----------------------|------------------|------------------------|-----------------------|------------------|-----------------------------------|----------------------------------------------|----------------------------------|------------------------------------------|
|                                                                                  | C                        | Si | Mn | Al    | N     | S+0.405Se | Other components                    |                                                  |                    | Temp. (°C)             | Rolling reduction (%) | Strain rate (/s) | Temp. (°C)             | Rolling reduction (%) | Strain rate (/s) |                                   |                                              |                                  |                                          |
| 28                                                                               |                          |    |    | 0.004 | 0.004 | 0.0040    | Ni:0.02, Sn:0.02, Bi:0.001          | 0.2                                              | two-pass rolling   | 1110                   | 32                    | 33               | 1085                   | 28                    | 25               | 27                                | -                                            | 0                                | 1.921                                    |
| 29                                                                               |                          |    |    | 0.005 | 0.003 | 0.0042    | P:0.04, Sb:0.03, Nb:0.003, Te:0.001 | 0.2                                              | two-pass rolling   | 1110                   | 32                    | 33               | 1085                   | 28                    | 25               | 27                                | -                                            | 0                                | 1.918                                    |
| Note: underlining indicates a value outside the scope of the present disclosure. |                          |    |    |       |       |           |                                     |                                                  |                    |                        |                       |                  |                        |                       |                  |                                   |                                              |                                  |                                          |

**[0075]** From Table 3, it can be seen that the Examples according to the present disclosure have improved production stability and also provide good magnetic properties.

#### INDUSTRIAL APPLICABILITY

**[0076]** According to the present disclosure, a hot-rolled coil with few surface defects is obtainable.

#### REFERENCE SIGNS LIST

**[0077]**

- 1 steel slab
- 2 skid
- 3 shift skid

#### Claims

1. A method of hot rolling comprising heating a steel slab in a heating furnace and then hot rolling, wherein,
  - in a temperature range T in which a temperature of the steel slab in the heating furnace is 950 °C or higher and 1150 °C or lower,
  - when heating the steel slab having a chemical composition in which a  $\gamma$  phase ratio is 20 mol% or less at 1050 °C, which is the median value of the temperature range T, and when using the heating furnace in which a distance between skids supporting the steel slab exceeds 1.1 m,
  - an average oxygen concentration in the heating furnace in the temperature range T is 5.0 vol% or less.
2. The method of hot rolling according to claim 1, wherein the average oxygen concentration in the heating furnace in the temperature range T is 3.0 vol% or less.
3. The method of hot rolling according to claim 1 or 2, wherein the hot rolling includes two consecutive passes of hot rolling, each pass being carried out in a temperature range from 1030 °C to 1150 °C, under conditions of a rolling reduction of 50 % or lower and a strain rate of 15/s or more, and a time between the two consecutive passes is 15 s or longer.
4. A method of producing a grain-oriented electrical steel sheet, the method comprising: hot rolling a steel slab by the method of hot rolling according to any one of claims 1 to 3; hot-rolled sheet annealing an obtained hot-rolled coil; then cold rolling once or cold rolling twice or more with intermediate annealing; then optionally carrying out decarburization annealing; and then carrying out final annealing to obtain a grain-oriented electrical steel sheet.
5. A hot-rolled coil for a grain-oriented electrical steel sheet, the hot-rolled coil obtained by hot rolling a steel slab by the method of hot rolling according to any one of claims 1 to 3, wherein a number of surface defects in a range of  $L_0$  m before and after a rolling direction of the hot rolling with respect to a location corresponding to a position on a skid when the steel slab was heated is on average 0.3 or less,
  - where  $L_0$  m is derived from the following expression (1) where X is a width of the skid,  $Y_1$  m is a thickness of the steel slab, and  $Y_2$  m is a thickness of the hot-rolled coil for a grain-oriented electrical steel sheet,

$$L_0 \text{ m} = \{0.15 \text{ m} + X \text{ m}\} \times Y_1 \text{ mm} / Y_2 \text{ mm} \quad (1).$$

FIG. 1

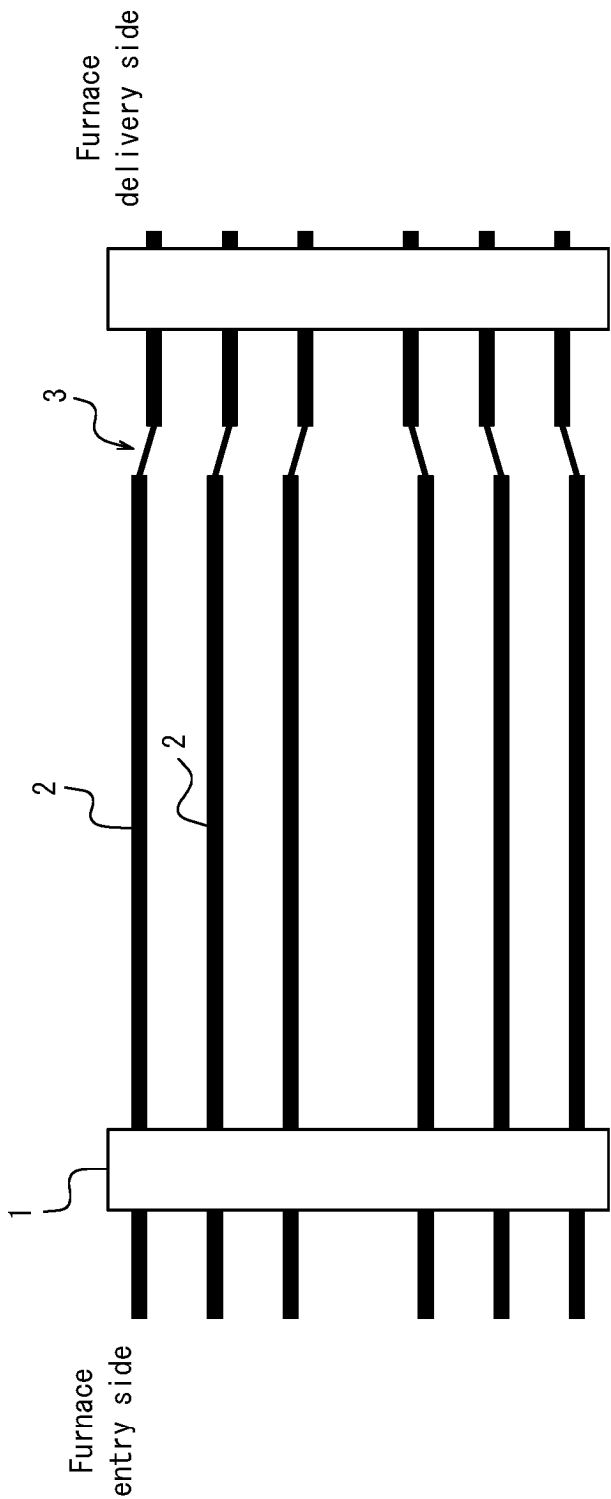
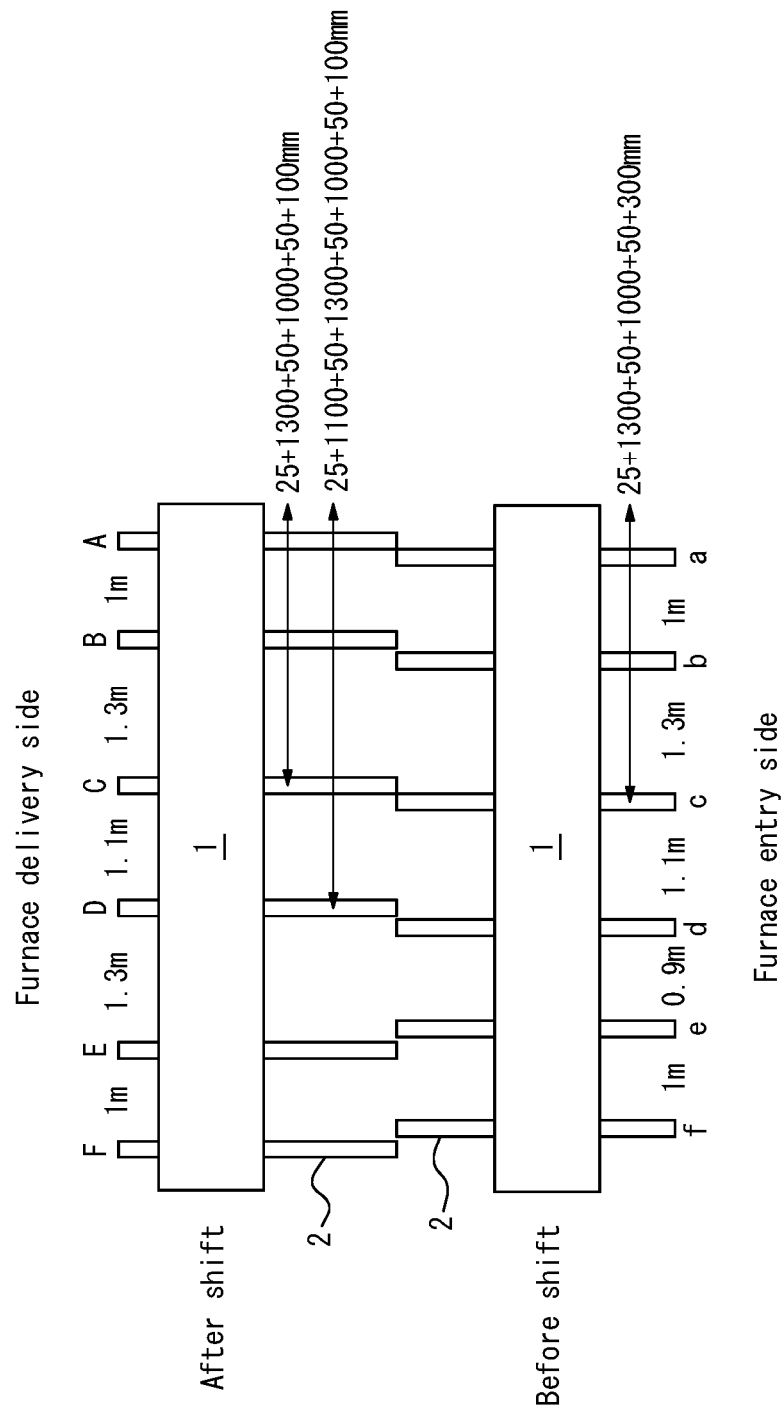


FIG. 2



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2024/040885

## A. CLASSIFICATION OF SUBJECT MATTER

**C21D 8/12**(2006.01)i; **B21B 1/26**(2006.01)i; **B21B 3/02**(2006.01)i; **C21D 9/00**(2006.01)i; **C22C 38/00**(2006.01)i;  
**C22C 38/60**(2006.01)i; **H01F 1/147**(2006.01)i

FI: C21D8/12 B; C21D9/00 101A; B21B3/02; B21B1/26 D; H01F1/147 175; C22C38/00 303U; C22C38/60

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C21D8/12; B21B1/26; B21B3/02; C21D9/00; C21D9/46; C22C38/00-C22C38/60; H01F1/147

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996  
 Published unexamined utility model applications of Japan 1971-2025  
 Registered utility model specifications of Japan 1996-2025  
 Published registered utility model applications of Japan 1994-2025

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                        | Relevant to claim No. |
|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Y         | JP 2004-291051 A (JFE STEEL CORPORATION) 21 October 2004 (2004-10-21)<br>claims, paragraphs [0027]-[0028], table 1                                                                                                                                        | 1-2, 4                |
| A         |                                                                                                                                                                                                                                                           | 3, 5                  |
| Y         | Microfilm of the specification and drawings annexed to the request of Japanese Utility Model<br>Application No. 144734/1977 (Laid-open No. 70907/1979) (KAWASAKI STEEL CORP.) 19<br>May 1979 (1979-05-19), claims, p. 2, line 2 to p. 4, line 4, fig. 1-2 | 1-2, 4                |
| A         |                                                                                                                                                                                                                                                           | 3, 5                  |
| X         | JP 52-105507 A (KAWASAKI STEEL CORP.) 05 September 1977 (1977-09-05)<br>claims, p. 1, lower left column, lines 13-15, p. 2, upper left column, line 10 to lower right<br>column, line 16                                                                  | 5                     |
| A         |                                                                                                                                                                                                                                                           | 1-4                   |
| A         | JP 60-114518 A (KAWASAKI STEEL CORP.) 21 June 1985 (1985-06-21)<br>entire text, all drawings                                                                                                                                                              | 1-5                   |



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents:

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“P” document published prior to the international filing date but later than the priority date claimed

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“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

**03 February 2025**

Date of mailing of the international search report

**18 February 2025**

Name and mailing address of the ISA/JP

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 Japan**

Authorized officer

Telephone No.

## INTERNATIONAL SEARCH REPORT

International application No.

**PCT/JP2024/040885**

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                             | Relevant to claim No. |
|-----------|----------------------------------------------------------------------------------------------------------------|-----------------------|
| A         | US 4898628 A (ARMCO ADVANCED MATERIALS CORPORATION) 06 February 1990 (1990-02-06)<br>entire text, all drawings | 1-5                   |

INTERNATIONAL SEARCH REPORT  
Information on patent family members

International application No.  
**PCT/JP2024/040885**

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| Patent document<br>cited in search report | Publication date<br>(day/month/year) | Patent family member(s)                                                                    | Publication date<br>(day/month/year) |
|-------------------------------------------|--------------------------------------|--------------------------------------------------------------------------------------------|--------------------------------------|
| JP 2004-291051 A                          | 21 October 2004                      | (Family: none)                                                                             |                                      |
| JP 54-70907 U1                            | 19 May 1979                          | (Family: none)                                                                             |                                      |
| JP 52-105507 A                            | 05 September 1977                    | (Family: none)                                                                             |                                      |
| JP 60-114518 A                            | 21 June 1985                         | (Family: none)                                                                             |                                      |
| US 4898628 A                              | 06 February 1990                     | DE 4001524 A1<br>entire text, all drawings<br>BR 8906566 A<br>CA 2005027 A1<br>IN 171870 B |                                      |

**REFERENCES CITED IN THE DESCRIPTION**

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- JP S4015644 B [0006]
- JP S5113469 B [0006]
- JP 2000129356 A [0006]
- JP S5079442 A [0063]
- JP S4839338 A [0063]

**Non-patent literature cited in the description**

- database, TCFE7 [0011]