(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 875 586 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 158(3) EPC

(43) Date of publication:
04.11.1998 Bulletin 1998/45

(21) Application number: **96941184.2**

(22) Date of filing: **05.12.1996**

(51) Int. Cl.[6]: **C21D 8/12**

(86) International application number:
PCT/JP96/03570

(87) International publication number:
WO 97/20956 (12.06.1997 Gazette 1997/25)

(84) Designated Contracting States:
DE FR GB IT SE

(30) Priority: **05.12.1995 JP 316870/95**
08.12.1995 JP 345044/95
01.08.1996 JP 218096/96
05.08.1996 JP 206064/96
02.12.1996 JP 321886/96

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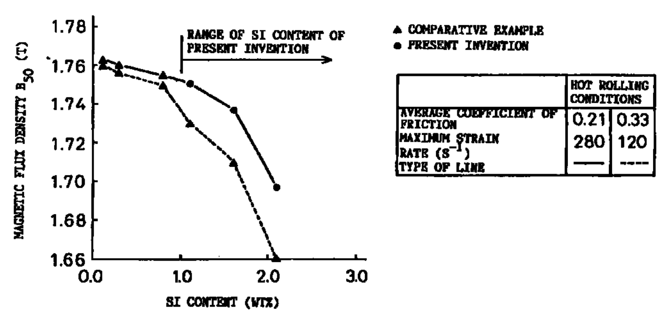
(54) PROCESS FOR PRODUCING NON-ORIENTED ELECTRICAL STEEL SHEET HAVING HIGH MAGNETIC FLUX DENSITY AND LOW IRON LOSS

(57) A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss comprising using a slab of steel containing 1.00% < Si ≤ 7.00%, 0.10% ≤ Mn ≤ 1.50%, C ≤ 0.0050%, N ≤ 0.0050%, S ≤ 0.0050%, and a balance of Fe and unavoidable impurities, hot rolling it to produce a hot rolled sheet, applying or not applying a hot rolled strip annealing process, applying one or two or more cold rolling processes with annealing step, then applying finishing annealing or then applying a skin pass rolling process, the method for producing a non-oriented electrical sheet characterized in that the average coefficient of friction between the hot rolling roll and steel sheet at the finish hot rolling is not more than 0.25 or the average coefficient of friction is not more than 0.25 and finish hot rolling is performed at a maximum strain rate of at least one pass of not less than 150 s^{-1}. Further, a method for production characterized by joining sheet bars at the rough rolling and using them for continuous finish hot rolling.

Fig.1



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Description

TECHNICAL FIELD

The present invention relates to a process for production of non-oriented electrical steel sheet having a high magnetic flux density, low iron loss, and superior magnetic properties which can be used as a core material of electrical appliances.

BACKGROUND ART

In recent years, in the fields of electrical appliances, in particular rotating machinery where non-oriented electrical steel sheet is used as the core material, and medium and small sized transformers etc., due to the global movement to conserve power and energy and the movement to protect the global environment such as restrictions on the use of fluorocarbon gas, efforts to increase efficiency has been rapidly spreading. Therefore, to reduce the energy loss at the time of use, that is, the watt loss, so as to increase efficiency, there have been increasing demands made by users for low iron loss electrical steel sheet. On the other hand, in rotating machines, a reduction in the size of the cores while securing the same output requires that the operating magnetic flux density be raised. Therefore, high magnetic flux density non-oriented electrical steel sheet is being demanded. This reduction in size of rotating machines leads to lighter weight of the vehicles on which they are themselves mounted, that is, automobiles and trains. This itself has the advantage of leading to a reduction of the energy consumed. Therefore, recently, there have been a strong demand, from users, for non-oriented electrical steel sheet having a low iron loss and high magnetic flux density.

Further, in the modern age where we have entered into an era of tremendous global competition, there are strong demands from users for reduction of the cost of non-oriented electrical steel sheet. Conversely, the fact is that users are selecting non-oriented electrical steel sheet which, while identical in price, is just a little better in magnetic properties.

In non-oriented electrical steel sheet, however, in the past, as the means for reducing the iron loss, a method had been adopted of increasing the content of Si, Al, etc. from the viewpoint of reducing the eddy current loss due to the increase in the electrical resistance. With this method, however, there was the problem that a reduction of the magnetic flux density was unavoidable. To overcome this problem, a method has been used to enlarge the crystal grain size of the hot rolled sheet mainly to improve the flux density.

In the past, in non-oriented electrical steel sheets with high Si contents, there was insufficient growth of the crystal structure after the finish hot rolling. To provide a material with a high magnetic flux density and low iron loss, it was considered essential to anneal the hot rolled steel sheet by some method after the end of the finish hot rolling so as to enlarge the crystal structure. While it became possible to improve the magnetic properties of the product somewhat by annealing the hot roiled steel sheet, however, this was not enough to meet the demands of users with regard to high magnetic flux density, low iron loss materials.

In view of these problems, in a high Si steel with an Si content of 2.5% to 4.0%, Japanese Unexamined Patent Publication (Kokai) No. 59-745 discloses the technique of not only defining the impurities in one cold rolling to limit them to S≤15 ppm, O≤20 ppm, and N≤25 ppm, but also defining the conditions of the annealing of the hot rolled sheet and defining the cold rolling reduction rate as not less than 65%, while Japanese Unexamined Patent Publication (Kokai) No. 59-74225 discloses the technique of not only defining the impurities in two steps cold rollings to S≤15 ppm, O≤20 ppm, and N≤25 ppm, but also defining the conditions of process annealing and defining the second cold rolling reduction rate as not less than 70%.

As shown in these prior applications, however, the techniques focusing on increasing the purity of the steel failed to solve the problem inherent to high Si type non-oriented electrical steel sheet of the insufficient improvement in the magnetic flux density despite the improvement of the iron loss.

Further, Japanese Unexamined Patent Publication (Kokai) No. 54-76422 discloses, as a technique for inexpensively enlarging the crystal structure before cold rolling a non-oriented electrical steel sheet to raise the magnetic flux density, a self annealing method where the hot rolled steel sheet after the finish hot rolling is coiled at a high temperature of 700°C to 1000°C and is annealed by the retained heat by the coil. Further, Japanese Examined Patent Publication (Kokoku) No. 62-61644 discloses a method for controlling temperature after the hot rolling a high temperature of not less than 1000°C, setting the non-water injection time, and promoting the recrystallization and grain growth of the hot rolled structure before coiling on a run-out table.

While crystal grain growth of the hot rolled structure can be promoted by this technique, however, the problem inherent to high Si type non-oriented electrical steel sheet of the insufficient improvement in the magnetic flux density could not be solved.

Further, as a technique for using controlled hot rolling for improving the magnetic properties of high Si type component high grade non-oriented electrical steel sheet with a slow progression of recrystallization and grain growth, Japanese Unexamined Patent Publication (Kokai) No. 59-74222 discloses a technique of controlling the reduction of the final stand in the finish hot rolling not less than 20% and also controlling the coiling temperature of the hot rolled sheet not less than 700°C. In this prior publications, the aim is to raise the reduction ratio at the final stand and raise the coiling temperature so as to promote recrystallization and grain growth of the hot rolled structure after the hot rolling and as a result improve the magnetic properties. When the Si content in the steel sheet is high, however, the subsequent grain growth is insufficient and therefore again the problem inherent to high Si type non-oriented electrical steel sheet of an insufficient improvement in the magnetic flux density is not solved.

As explained above, in the prior art, it was not possible to produce a high Si content high grade non-oriented electrical steel sheet with a sufficient magnetic flux density and low iron loss and it was therefore not possible to meet the demands of users for non-oriented electrical steel sheet.

DISCLOSURE OF THE INVENTION

The present invention differs in concept from that of the prior art and is based on the technical concept of reducing the average friction coefficient at the time of controlled rolling so as to deliberately cause the formation of a recovery structure and of suitably controlling the work deformation rate (strain rate) at the time of hot rolling so as to improve the aggregate structure near the surface of the steel sheet and as a result cause enlargement of the actual grain size of the hot rolled crystal structure and improve the aggregate structure before cold rolling. The object of this is to provide a process for production of a high Si content high grade non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss, which had been difficult in the prior art.

The gist of the present invention is as follows:

(1) A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss using a slab containing

$1.00\% < Si \leq 7.00\%$
$0.10\% \leq Mn \leq 1.50\%$
$C \leq 0.0050\%$
$N \leq 0.0050\%$
$S \leq 0.0050\%$

and a balance of Fe and unavoidable impurities, hot rolling it to produce a hot rolled steel sheet, applying one or two, or more cold rolling processes with a process annealing step, then carrying out finishing annealing,

said process for the production of a non-oriented electrical steel sheet characterized in that the average coefficient of friction between the hot rolling roll and steel sheet at the time of the finish hot rolling is not more than 0.25.

(2) A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss using a slab containing

$1.00\% < Si \leq 7.00\%$
$0.10\% \leq Mn \leq 1.50\%$
$C \leq 0.0050\%$
$N \leq 0.0050\%$
$S \leq 0.0050\%$

and a balance of Fe and unavoidable impurities, hot rolling it to produce a hot rolled steel sheet, applying one or two, or more cold rolling processes with a process annealing step, then carrying out finishing annealing,

said process for the production of a non-oriented electrical steel sheet characterized in that the average coefficient of friction between the hot rolling roll and steel sheet at the time of the finish hot rolling is not more than 0.25, and the strain rate of at least one pass in the finish hot rolling is at least 150 s^{-1}.

(3) A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss as set forth in claims (1) and (2) characterized in that the steel further contains, by wt%, $0.10\% \leq Al \leq 2.00\%$.

(4) A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss as set forth in claims (1), (2) and (3), characterized in that the hot rolled sheet is annealed after the finish hot rolling and before the cold rolling by continuous annealing at a temperature of 850°C to 1150°C for 20 seconds to less than 5 minutes.

(5) A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss as set forth in claims (1), (2) and (3), characterized in that the hot rolled sheet is annealed after the finish hot rolling and before the cold rolling by box annealing at a temperature of 750°C to 850°C for 5 minutes to less than

30 hours.

(6) A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss as set forth in claims (1), (2) and (3), characterized in that the hot rolled strip is coiled at a temperature of 750°C to 1000°C and self annealing is carried out by the heat retained by the coil itself for 5 minutes to 5 hours after the finish hot rolling.

(7) A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss as set forth in claims (1), (2) and (3), characterized in that strip coolant is not applied and the hot rolled strip is coiled during the time t (seconds) defined by the following formulas after the hot rolling at the temperature T (°C) of the finish hot rolling:

$$950 \leq T\ (^\circ C) \leq 1150 \qquad \text{Formula (1)}$$

$$9.6 - 8 \times 10 - 3T \leq t\ \text{(seconds)} \leq 15.6 - 8 \times 10 - 3T \qquad \text{Formula (2)}$$

(8) A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss as set forth in claims (1), (2), (3), (4), (5), (6) and (7), said method for producing a non-oriented electrical steel sheet comprising applying a skin pass rolling process of 2 to 20% after the finishing annealing.

(9) A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss as set forth in claims (1), (2), (3), (4), (5), (6), (7) and (8), characterized in that lubricant oil is added to the cooling water of the hot rolled roll in an emulsion state in a ratio of volume of 0.5 to 20% as a lubricant at the finish hot rolling.

(10) A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss as set forth in claims (1), (2), (3), (4), (5), (6), (7), (8) and (9), characterized by welding the sheet bar after the rough rolling with the preceding sheet bar before the finish hot rolling to weld the sheet bars and performing the finish hot rolling on the same.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a view of the relationship between the Si content and the magnetic flux density.

Figure 2 is a view of the relationship between the average coefficient of friction at the finish hot rolling and the magnetic flux density of the product.

Figure 3 is a view of the relationship between the strain rate of the final stand at the finish hot rolling and the magnetic flux density of the product.

Figure 4 is a view of the relationship between the average coefficient of friction and maximum strain rate of all of the stands at the finish hot rolling and the magnetic flux density of the product.

Figure 5 is a view of the relationship between the average coefficient of friction at the finish hot rolling and the magnetic flux density of the product after annealing of the hot rolled steel sheet.

Figure 6 is a view of the relationship between the average coefficient of friction and maximum strain rate of all of the stands at the finish hot rolling in the annealing process of the hot rolled sheet by continuous annealing and the magnetic flux density of the product.

Figure 7 is a view of the relationship between the annealing a hot rolled steel sheet by continuous annealing and the magnetic flux density of the product.

Figure 8 is a view of the relationship between the temperature of annealing a hot rolled steel sheet by continuous annealing and the magnetic flux density of the product.

Figure 9 is a view of the relationship between the average coefficient of friction at the hot rolling and the magnetic flux density of the product which has been self annealed.

Figure 10 is a view of the relationship between the average coefficient of friction at the hot rolling and the magnetic flux density of the product which has not been subjected to strip coolant application for a certain period of time after hot rolling.

Figure 11 shows electron micrographs of the changes in the crystal structure of the hot rolled steel sheet due to differences in the coefficient of friction, wherein Figs. 11A and 11C show the present invention and Figs. 11B and 11D show comparative examples.

Figure 12 shows electron micrographs of the changes in the crystal structure after annealing of the hot rolled steel sheet due to differences in the coefficient of friction, wherein Fig. 12A shows the present invention and Fig. 12B shows a comparative example.

BEST MODE OF WORKING THE INVENTION

The present invention will be explained in detail below.

The present inventors engaged in intensive studies to overcome the limit of controlled rolling of such a high Si content non-oriented electrical steel sheet and as a result discovered that by either hot rolling a steel containing more than 1.0% to 7.0% of Si, 0.1% to 1.5% of Mn, and, if necessary, 0.10% to 2.0% of Al by an average coefficient of friction between the hot rolling roll and steel sheet at the finish hot rolling of not more than 0.25 or by further suitably controlling the work deformation rate at the hot rolling (strain rate) in addition to the average coefficient of friction in the hot rolling, the formation of a fine grain structure caused by the recrystallization of the surface of the hot rolled steel sheet is suppressed and a rough recovered structure is obtained over the entire thickness of the steel sheet.

Further, the inventors made the completely novel discovery that this recovered structure is a structure rougher than even the recovered structure seen in the center layer of the hot rolled steel sheet obtained by a conventional high coefficient of friction rolling method and as a result that a rough crystal structure can be substantially obtained over the entire thickness of the sheet.

Further, the inventors made the completely novel discovery that even in a process predicated on various types of annealing of hot rolled steel sheets, a process of self annealing by high temperature coiling, and a process of high temperature finishing setting a non-water coolant period, by hot rolling at an average coefficient of friction between the hot rolling roll and the steel sheet at the finish hot rolling of not more than 0.25 or further suitably controlling the work deformation rate at the time of hot rolling (strain rate) in addition to the average coefficient of friction in the hot rolling, crystal grain growth at the time of the annealing of the hot rolled sheet, at the time of the self annealing with the objective of replacing annealing of the hot rolled sheet, or at the time of the high temperature finishing setting a non-water coolant application period, is promoted.

In this way, the technical concept of the present invention is a completely different technical concept from the conventional reduction of the coefficient of friction at the time of finish hot rolling to positively promote the formation of a recovered structure and at the same time maintain the strain rate at the finish hot rolling at a certain level or more so as to further promote this effect.

Further, the inventors discovered that as a means for lubricant rolling as in the present invention, it is effective to mix a certain amount or more of lubricant oil in the coolant (cooling water) for the rolling roll and apply it on the work roll.

Further, the inventors discovered that to stably perform the finish hot rolling at a low friction rate, as in the present invention, it is effective to weld the sheet bar after rough rolling with the preceding sheet bar and continuously perform the finish hot rolling.

By using a hot rolled steel sheet obtained by this process as a starting material, they succeeded in producing a non-oriented electrical steel sheet with an extremely high magnetic flux magnetic density and an excellent iron loss (low iron loss value) in a product after finishing annealing.

First, to explain the composition, Si is added to increase the inherent resistance of the steel sheet, reduce the eddy current loss, and improve the iron loss value. If the Si content is less than 1.0%, even if the coefficient of friction at the finish hot rolling is reduced and the strain rate is controlled, the effect of improvement of the magnetic flux density is small. Further, the inherent resistance required for the low iron loss non-oriented electrical steel sheet aimed at by the present invention cannot be sufficiently obtained, so it is necessary to add an amount of over 1.0%. On the other hand, if the Si content is over 7.0%, the edge cracking at the not rolling remarkably increases and rolling operation becomes difficult, so it is necessary to contain it not more than 7.0%.

The following experiment was performed to investigate the dependency of the effect of improvement of the magnetic properties of the present invention on the Si content. The steel composition of non-oriented electrical steel sheets with different Si contents were melted and subjected to finish rolling.

As the amount of other components other than Si, Mn was controlled to 0.1 to 0.2%, the sol-Al to not more than 20 ppm, and the C, N, and S to 10 to 20 ppm each. The steel compositions were adjusted to clarify the relationship between the effect of the present invention and the Si content.

First, in the examples of the present invention, the average coefficient of friction at the finish hot rolling was made 0.21 by adjusting the content of the lubricant oil in the coolant to 2.5% by percent volume. The average coefficient of friction was found by calculating the coefficients from the actually measured forward slip ratio of the stands and finding the average of the same. Further, the strain rate of the final stand in the finishing mill was made 280 s^{-1}.

Further, as comparative examples, steels of different compositions were rolled by adjusting the content of lubricant oil in the coolant to 0.3% by percent volume to make the average coefficient of friction at the time of the finish hot rolling 0.33, adjusting the pass schedule so that the maximum strain rate is given at the final stand, and controlling that value to 120 s^{-1}.

The temperature at the end of the finish hot rolling was made a constant 860°C in all cases and the hot rolled sheets in all cases were finished to a thickness of 2.5 mm.

The above hot rolled strip were then pickled and cold rolled to a thickness of 0.50 mm, then annealed in a continuous annealing furnace, and then Epstein specimens were cut out and the magnetic properties were measured.

The dependency of the magnetic flux density of the products, obtained as a result of the experiments, on the Si content is shown in Fig. 1. Even in the low Si region, a slight effect of improvement of the magnetic properties was observed, but it was learned that as the Si content became higher, the effect of improvement of the magnetic properties of the present invention became greater and that the increase was remarkable when the Si content was over 1%. The range of the Si content defined in the present invention was made at least 1.0% not only for securing the above-mentioned inherent resistance of the steel sheet, but also because this was the Si content effectively giving the hot rolling conditions of the present invention.

Al also, like Si, has the effect of increasing the inherent resistance of the steel sheet and reducing the eddy current loss. To obtain the low iron loss and high magnetic flux density of non-oriented electrical steel sheet aimed at by the present invention, at least 0.1% must be added. On the other hand, if the Al content is over 2.0%, the magnetic flux density falls and the cost rises, so the Al content limit not more than 2.0%.

Further, even if the Al content in the steel is less than 0.10%, the effect of the present invention is not impaired in any way.

Mn like Al and Si has the effect of increasing the inherent resistance of the steel sheet and reducing the eddy current loss. For this purpose, the Mn content must be limited to at least 0.10%. By the present invention, it is possible to provide high magnetic flux density and low iron loss non-oriented electrical steel sheet even better than the prior art, therefore for applications where a certain level of magnetic properties and electrical resistivity are required, normally the Mn content of 0.1% to 1.0% is sufficient. However, for applications where even better magnetic properties and electrical resistivity, in particular, both a high magnetic flux density and a low iron loss, are required, it is preferable to contain 1.0% to 1.5% of Mn. On the other hand, if the Mn content is over 1.5%, the deformation resistance at the time of hot rolling increases and hot rolling becomes difficult. Also, the crystal structure after the hot rolling easily becomes fine and the magnetic properties of the product deteriorate, so the Mn content must be limited to less than 1.5%.

Further, the amount of Mn added is extremely important from the viewpoint of ensuring the strength of the welded parts of the sheet bars at a high temperature before the finish hot rolling. The reason is that to prevent hot shortness of the welded parts of the sheet bars due to the presence of low melting point sulfides at the crystal grain boundaries, it is necessary to make the ratio of the concentration by weight of the Mn and S, that is, the Mn/S value, at least 20. In the range of composition defined in the present invention, the Mn content is not less than 0.1% and the S content is not more than 0.005%, so the Mn/S value is held at 20 or more. There is no problem from this viewpoint.

Further, even if one or more types of P, B, Ni, Cr, Sb, Sn, and Cu are added into the steel to improve the mechanical properties of the product, to improve the magnetic properties and the rust resistance, and for other objectives, the effect of the present invention is not impaired.

If the C content exceeds 0.0050%, the magnetic aging during use causes the iron loss to deteriorate and increases the energy loss at the time of use, so it is necessary to control it to not more than 0.0050%.

S and N partially re-dissolve during the slab heating in the hot rolling process and form MnS and other sulfides and AlN and other nitrides during the hot rolling. These obstruct grain growth of the hot rolled structure due to their presence and obstruct the crystal grain growth at the time of the finishing annealing causing the iron loss to deteriorate, so it is necessary to control the S not more than 0.0050% and the N not more than 0.0050%.

Next, the processes in the present invention will be explained.

The value of the coefficient of friction between the rolling roll and steel sheet at the hot rolling should be not more than 0.25 in terms of the average value for all stands in the finish hot rolling. If the coefficient of friction over 0.25, the effect is insufficient and the magnetic flux density of the product decreases. The lower limit of the coefficient of friction is not particularly decided, but if the value is excessively small, slip occurs during the rolling and stable rolling no longer becomes possible, so it is preferably set to not less than 0.05.

The amount of the lubricant oil mixed with the coolant for rolling roll at the finish hot rolling is made 0.5% to 20% by percent volume. The oil is mixed in an emulsion state. If the amount of the lubricant oil in the coolant is less than 0.5%, the effect is not obtained, while if over 20%, the effect becomes saturated and becomes uneconomical, so the upper limit is made 20%. In accordance with need, a surfactant may be added to prevent separation of the lubricant oil and cooling water. Further, the emulsion mixed state may be created by feeding the lubricant oil and cooling water by separate systems of piping and simultaneously spraying the rolling roll with the lubricant oil and cooling water from the same spray nozzles.

As the lubricating oil, a known hot rolling oil for finishing mills should be used. As examples of the hot rolling oil for finishing mills, Kyudoru 5149®, Kyudoru 0B068®, and Kyudoru 4B313® all brand names of Kyodo Yushi Co.) may be mentioned.

When performing the finish hot rolling at a low friction rate or low friction rate and high strain rate as in the present invention, at the time the sheet bar is rolled by the finishing mill, occluding defects of the sheet bar occur, slip occurs between the roll and the steel sheet during the finish hot rolling, the lifetime of the rolling roll is remarkably shortened, and deep rolling defects are caused in the surface layer of the steel sheet. As a method to solve these problems in finish hot rolling at such a low friction rate or low friction rate and high strain rate and stabilize the operation, it is particularly effective to weld the sheet bar after rough rolling to the preceding sheet bar before the finish hot rolling and continuously supply the sheet bars to the finish hot rolling.

As a method for bonding the preceding sheet bar and the succeeding sheet bar, there are the method of aligning the rear end of the preceding sheet bar and the front end of the succeeding sheet bar and applying a pressing force to the aligned portion to join them, the method of applying a pressing force to the aligned portion and laser welding it, the method of induction heating the aligned portion to bond it, etc.

In the present invention, by making the strain rate of at least one pass in the finish hot rolling at least 150 s^{-1}, it is possible to improve the magnetic properties more. There is no particular upper limit set on the strain rate. The reason is that the upper limit of the strain rate is inherently determined from the capabilities of the rolling mill and the controllability of the shape of the hot rolled steel sheet. That is, the strain rate is determined by the rolling speed, the hot rolling roll diameter, and the amount of the reduction ratio. If the rolling speed and the amount of the reduction ratio are made larger, the strain rate increases, but control of the shape of the hot rolled sheet becomes difficult. Since a non-oriented electrical steel sheet is supplied for use stacked with other sheets, strict control of its shape is required. Therefore, there are inherent limits to the increase of the strain rate. From this viewpoint, there is a limit of about 600 s^{-1} on the strain rate.

The pickled hot rolled sheet may be annealed by continuous annealing or box annealing. Further, the hot rolled strip may be coiled at a temperature of 750°C to 1000°C and self-annealed by the heat which the coil itself retains for 5 minutes to 5 hours. Alternatively, the strip may be coiled without coolant for a period of time defined by a specific equation after the end of the hot rolling.

The hot rolled sheet obtained in this way may be subjected to one cold rolling process and then finishing annealing or may be subjected to two or more cold rolling processes including a process annealing step and then finishing annealing. Further, rolling for finishing the sheet to the final thickness may be performed by the known cold rolling technique, but in the case of a high Si composition system, to prevent breakage or edge cracking during rolling, it is also possible to raise the temperature of the steel sheet in accordance with the Si content and immerse the coil in warm water or perform warm rolling at 100 to 400°C.

Further, after that, it is possible to perform a skin pass rolling process to make the final product. When adding a skin pass rolling process, an effect is not obtained if a reduction ratio of the skin pass rolling is less than 2% and the magnetic properties deteriorate it it is over 20%, so the reduction ratio is made 2% to 20%.

Next, the detailed conditions of the processes defined by the present invention will be explained.

<u>Effect of Coefficient of Friction at Time of Finish hot rolling on Magnetic Properties in Process Omitting Annealing of Hot Rolled Sheet</u>

First, the conditions of the processes of the present invention in the case of omitting the annealing of the hot-rolled sheet will be explained.

A steel slab comprised of the above composition is produced by melting by a converter and continuous casting or ingot-making and slabbing. The steel slab is re-heated by a known method. This slab is then hot rolled to a predetermined thickness.

In the finish hot rolling, lubricant oil is mixed into the coolant to reduce the coefficient of friction between the work roll of the finish hot rolling mill and the steel sheet. A surfactant is added in accordance with need to prevent the lubricant oil and the cooling water from separating. At the finish hot rolling, the amount of the lubricant oil mixed into the cooling water is made 0.5% to 20% by percent volume. If the amount of the lubricant oil in the cooling water is less than 0.5%, an effect is not obtained, while if it is over 20%, the effect becomes saturated so the result is uneconomical, therefore the amount is made more than 0.5% and less than 20%.

The following experiment was carried out to investigate the effect of the average coefficient of friction between the hot rolling work roll and steel sheet at the finish hot rolling. Steel composition shown in Table 1 was melted and cast, and then subjected to rough hot rolling and finish hot rolling.

The average coefficient of friction at the finish hot rolling was changed from 0.1 or so to over 0.3 by changing the content of the lubricant oil in the cooling water. The average coefficient of friction was found by calculating the coefficients from the actually measured forward slip ratio of the mill stands and finding the average of the same. The temperature at the end of the finish hot rolling was maintained at a temperature of 860°C and the sheet finished to a thickness of 2.0 mm. The hot rolled strip was then pickled and cold rolled to a thickness of 0.35 mm, then annealed for 30 seconds at 900°C in the case of the steel A and 980°C in the case of the steel B, then Epstein specimens were cut out and measured for magnetic properties.

The dependency of the magnetic flux density of the product on the average coefficient of friction at the finish hot rolling is shown in Fig. 2. As the average coefficient of friction, the average of the actually measured values of the stands of the finish hot rolling mill was used. If the average coefficient of friction at the finish hot rolling is less than 0.25, it was learned that the magnetic flux density of the product rises. To clarify the reason for this phenomenon, the metallic structure of the hot rolled steel sheet of the steel A was observed by an electron microscope. The results are shown in Fig. 11. As shown in Figs. 11A and C, in the hot rolled steel sheet of the steel A of the present invention with an average friction coefficient of 0.21, both the surface layer and center of the sheet thickness are rough structures comprised of elongated grains. As opposed to this, as shown in Figs. 11B and D, in a hot rolled steel sheet of the steel A of the comparative example with an average coefficient of friction of about 0.35, an equiaxed grain structure comprised of a recrystallized structure is seen at a depth near one-tenth of the sheet thickness from the surface layer, the crystal structure becomes refine and refined recrystallized grains are seen near the center of the sheet thickness, and the grain boundary density becomes high.

These changes in the hot rolled crystal structure are believed to be due to the fact that, by reducing the average coefficient of friction at the finish hot rolling, the shear strain occurring in the steel sheet drops and a similar effect when hot rolling at a low rolling speed, is obtained and that the lattice defect density in the steel sheet drops, so the crystal structure does not recrystallize and becomes a recovered structure comprised of rough elongated grains and an effect is obtained that the grain size of the hot rolled structure is substantially increased.

In this way, the inventors succeeded in developing a means for improving the magnetic properties of high Si type non-oriented electrical steel sheet, in particular the magnetic flux density, by a technical concept completely different from the promotion of recrystallization and grain growth by raising the temperature at the final hot rolling in the prior art, that is, by suppressing the hot rolled crystal structure by the means of reducing the average coefficient of friction between the steel sheet and work roll at the finish hot rolling.

As shown by the above experiments, the value of the average coefficient of friction between the rolling roll and steel sheet at the finish hot rolling should be no more than 0.25 in terms of the average for all stands in the finish hot rolling. If the average coefficient of friction value is above 0.25, as explained above, the occurrence of recrystallized grains causes the crystal structure near the surface layer of the hot rolled steel sheet to become particularly finer and the magnetic flux density of the product to decline. There is no particular lower limit set on the coefficient of friction, but if the value becomes excessively small, slip occurs during rolling and stable hot rolling no longer becomes possible, so at least 0.05 is preferable.

The hot rolled sheet obtained in this way is then subject to one cold rolling process and then finishing annealing or two or more cold rolling processes including annealing, then finishing annealing.

Further, it is possible to then perform a skin pass rolling process to produce the final product.

Table 1

Composition of Material Used						
	C	Si	Mn	S	sol-Al	N
Steel A	0.0018	2.10	0.19	0.0019	0.30	0.0015
Steel B	0.0015	3.00	0.10	0.0015	0.70	0.0017

<u>Effect of Maximum Strain Rate at Finish hot rolling on Magnetic Properties in Process Omitting Annealing of Hot Rolled Steel Sheet</u>

Next, an explanation will be made of the effect of the strain rate on the effect of the present invention.

The following experiments were performed to investigate the effect of the strain rate of a pass at the finish hot rolling on the magnetic properties of the product. The steel composition shown in Table 2 was melted and subjected to finish hot rolling.

Table 2

Composition of Material Used					
C	Si	Mn	S	Al	N
0.0019	2.10	0.11	0.0017	0.24	0.0018

The rolling speed and pass schedule were changed for tests to change the strain rate at the finish hot rolling. The pass schedule was adjusted so that the maximum strain rate was obtained in the final stand. The temperature at the end of the finish hot rolling was 860°C. The steel sheet was finished to a thickness of 2.5 mm, water cooled, then coiled at 650°C.

The average coefficient of friction at the finish hot rolling was controlled to 0.20 by changing the content of the lubricant oil in the cooling water. The average coefficient of friction was found by calculating the coefficients from the actually measured forward slip ratio in the mill stands and taking the average value of the same.

Thus obtained hot rolled steel sheet was pickled, cold rolled to a thickness of 0.50 mm, then annealed at 950°C for 30 seconds. Epstein specimens were cut off and the magnetic properties measured.

The dependency of the magnetic flux density of the product on the strain rate of the final pass at the finish hot rolling is shown in Fig. 3. According to Fig. 3, it is learned that the magnetic flux density of the product rises with a strain rate of not less than 150 s^{-1}.

Note that the strain rate was calculated by the following formula. Here, r is the reduction ratio in %/100, n is the rotational speed of the roll (rpm), R is the radius of the rolling roll (mm), and H_0 is the sheet thickness before rolling (mm).

$$\text{Strain rate} = (2\pi n/(60r^{0.5}))(R/H_0)^{0.5}\ln(1/(1-r))$$

As shown in the above experiment, the strain rate in at least one pass in the finish hot rolling should be at least 150s^{-1}. No upper limit is set on the strain rate. The reason is that the upper limit of the strain rate is inherently determined from the capabilities of the mill and the controllability of the shape of the hot rolled steel sheet. That is, the strain rate is determined by the rolling speed, the hot rolling roll diameter, and the reduction ratio. If the rolling speed and the reduction ratio are made larger, the strain rate increases, but control of the shape of the hot rolled steel sheet becomes difficult. Since non-oriented electrical steel sheet is supplied for use stacked with other sheets, strict control of its shape is required. Therefore, there are inherent limits to the increase of the strain rite. From this viewpoint, there is a limit of about 600 s^{-1} on the strain rate.

The hot rolled steel sheet obtained in this way may be subjected to one cold rolling process and then final annealing and then further a skin pass rolling process.

Further, for the stable finish hot rolling at a high strain rate and a low friction rate as in the present invention, it is particularly effective to weld the sheet bar after rough rolling to the preceding sheet bar and continuously supply the sheet bars to the finish hot rolling.

As a method for welding the preceding sheet bar and the succeeding sheet bar, there are the method of aligning the rear end of the preceding sheet bar and the front end of the succeeding sheet bar and applying a pressing force to the aligned portion to join them, the method of applying a pressing force to the aligned portion and laser welding it, the method of induction heating the aligned portion to join it, etc.

Effect of Average Coefficient of Friction and Maximum Strain Rate at Finish hot rolling on Magnetic Properties in Process Omitting Annealing of Hot Rolled Sheet

Next, the following experiment was performed to explain the effect of the average coefficient of friction at the time of finish hot rolling and the maximum strain rate simultaneously on the effect of the present invention. The steel composition shown in Table 2 was melted and subjected to finish hot rolling.

The rolling rate and pass schedule were changed for tests to change the strain rate at the finish hot rolling. The pass schedule was adjusted so that the maximum strain rate was obtained in the final stand. The strain rate was calculated by the following formula. Here, r is the reduction ratio in %/100, n is the rotational speed of the roll (rpm), R is the radius of the rolling roll (mm), and H_0 is the sheet thickness before rolling (mm).

$$\text{Strain rate} = (2\pi n/(60r^{0.5}))(R/H_0)^{0.5}\ln(1/(1-r))$$

The average coefficient of friction at the time of finish hot rolling was controlled by changing the content of the lubricant oil in the cooling water. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forward slip ratio for the stands and finding the average value.

The temperature at the end of the finish hot rolling was 860°C. The sheet was finished to a thickness of 2.5 mm, water cooled, then coiled at 650°C.

This was then pickled and cold rolled to a thickness of 0.35 mm, stripped, then annealed for 30 seconds at 950°C. Epstein specimens were cut out and measured for magnetic properties.

Figure 4 shows the relationship between the average coefficient of friction and strain rate at the time of finish hot rolling at the time of hot rolling and the magnetic flux density of the product. As will be understood from Fig. 4, a high magnetic flux density of at least 1.68T is obtained in the region of the range defined by the present invention, that is, an average coefficient of friction of not more than 0.25 and a maximum strain rate of not less than 150s^{-1}.

Process Including Annealing of Hot Rolled Steel Sheet by Continuous Annealing or Box Annealing

Next, the following experiment was performed to investigate the effect of the average coefficient of friction between the hot rolling roll and steel sheet at the finish hot rolling on the magnetic properties of the product in the case of annealing the hot rolled steel sheet before the cold rolling. Steel composition shown in Table 3 was melted and subjected to finish hot rolling.

The coefficient of friction at the finish hot rolling was changed from 0.1 or so to at least 0.3 by changing the content of the lubricant oil in the cooling water. The average coefficient of friction was found by calculating the coefficients from the actually measured forward slip ratio of the stands and finding the average of the same. The temperature at the end of the finish hot rolling was maintained a constant 900°C and the steel sheet finished to a thickness of 2.0 mm. After the hot rolling was finished, it was quenched and coiled at 500°C.

This hot rolled coil was annealed in a continuous annealing furnace for 90 seconds at 950°C in the case of the steel C and at 980°C in the case of the steel D. This was then pickled and cold rolled to a thickness of 0.35 mm, then annealed for 30 seconds at 900°C in the case of the steel C and 980°C in the case of the steel D, then Epstein specimens were cut out and measured in magnetic properties.

The dependency of the magnetic flux density of the product on the average coefficient of friction at the finish hot rolling is shown in Fig. 5. As the average coefficient of friction, the average of the actually measured values of the stands of the finish hot rolling mill was used. From Fig. 5, it is learned that the magnetic flux density of the product rises if the average coefficient of friction at the finish hot rolling is not more than 0.25.

As shown in the above experiment, the value of the coefficient of friction between the rolling roll of the finish hot rolling and the steel sheet should be not more than 0.25 in terms of the average value for all of the stands at the finish hot rolling. If above 0.25, the effect is not sufficient and the magnetic flux density of the product falls.

Table 3

Composition of Material Used						
	C	Si	Mn	S	sol-Al	N
Steel C	0.0018	2.10	0.19	0.0019	0.30	0.0015
Steel D	0.0015	3.00	0.10	0.0015	0.70	0.0017

When performing the finish hot rolling at a low friction rate as in the present invention, the sheet bar is hot rolled by the finishing mill, rolling defects of the sheet bar occur, slip occurs between the roll and the steel sheet during the finish hot rolling, the lifetime of the rolling roll is remarkably shortened, and deep rolling defects are caused in the surface layer of the steel sheet. As a method to solve these problems in finish hot rolling at such a low friction rate and stabilize the operation, it is particularly effective to weld the sheet bar after rough rolling to the preceding sheet bar before the finish hot rolling and continuously supply the sheet bars to the finish hot rolling.

Further, the effect of the hot rolling conditions on the metal structure after annealing of the hot rolled steel sheet was investigated. Steel composition of the steel C of the composition of Table 3 was melted and subjected to finish hot rolling.

First, as an example of the present invention, the average coefficient of friction at the finish hot rolling was made 0.21 by making the content of the lubricant oil in the cooling water 2% by percent volume and the maximum strain rate was made 270 s^{-1} in the final stand. On the other hand, as a comparative example, the average coefficient of friction at the finish hot rolling was adjusted to 0.35 by making the content of the lubricant oil in the cooling water 0.3% and the maximum strain rate was made 120 s^{-1} in the final stand. The average coefficient of friction was found by calculating the coefficients from the actually measured forward slip ratio in the stands and taking the average value of the same. The temperature at the end of the finish hot rolling was kept a constant 860°C in both cases and the steel sheet finished to a thickness of 2.3 mm. The hot rolled steel sheet was annealed in a continuous annealing furnace at 950°C for 90 seconds. Specimens were cut out from the resultant hot rolled steel sheet and the metal structure of the hot rolled steel sheet observed by an electron microscope. The results are shown in Fig. 12. As shown in Fig. 12A, in the present invention, where the average coefficient of friction is low and the strain rate is high, the metal structure after annealing of the hot rolled steel sheet becomes coarser than the comparative example shown in Fig. 12B. As a result, it was observed that the magnetic properties of the product after annealing were improved.

These changes in the hot rolled crystal structure after the annealing of the hot rolled steel sheet are believed to partially result from the reduction of the average coefficient of friction at the finish hot rolling and the resultant suppression of the recrystallization of the crystal structure and generation of a larger accumulated strain and an increase in the force driving the grain growth at the annealing of the hot rolled steel sheet. Further, it is believed that increasing the strain rate creates a larger accumulated strain and further promotes the above effect.

Next, the following experiment was performed to explain the effect of the average coefficient of friction at the finish hot rolling and the maximum strain rate simultaneously on the effect of the present invention in the case of annealing the hot rolled steel sheet before cold rolling. The steel composition shown in Table 4 was melted and subjected to finish hot rolling.

The rolling speed rate and pass schedule were changed for tests to change the strain rate at the finish hot rolling. The pass schedule was adjusted so that the maximum strain rate was obtained in the final stand. The strain rate was calculated by the following formula. Here, r is the reduction ratio in %/100, n is the rotational speed of the roll (rpm), R is the radius of the rolling roll (mm), and H_0 is the thickness of the steel sheet before rolling (mm).

$$\text{Strain rate} = (2\pi n/(60r^{0.5}))(R/H_0)^{0.5}\ln(1/(1-r))$$

The average coefficient of friction at the finish hot rolling was controlled by changing the content of the lubricant oil in the cooling water. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forward slip ratio for the stands and finding the average value.

The temperature at the end of the finish hot rolling was 900°C. The sheet was finished to a thickness of 2.5 mm, water cooled, then coiled at 650°C. The hot rolled steel sheet was then annealed in a continuous annealing furnace at 930°C for 2 minutes.

The obtained hot rolled steal sheet was pickled and cold rolled to a thickness of 0.50 mm, then annealed for 30 seconds at 900°C. Epstein specimens were cut out and measured in magnetic properties.

Figure 6 shows the relationship between the average coefficient of friction and strain rate at the finish hot rolling and the magnetic flux density of the product. As will be understood from Fig. 6, a high magnetic flux density of at least 1.72T is obtained in the region of the range defined by the present invention, that is, an average coefficient of friction of not more than 0.25 and a maximum strain rate of not less than $150 s^{-1}$.

Table 4

Composition of Material Used					
C	Si	Mn	S	sol-Al	N
0.0011	2.50	0.20	0.0013	0.23	0.0011

Next, the following experiment was performed to investigate the effect of the annealing the hot rolled steel sheet and the temperature for annealing the hot rolled steel sheet by continuous annealing on the magnetic flux density. Steel C of the composition of Table 5 was melted and subjected to finish hot rolling.

The content of the lubricant oil in the cooling water at the finish hot rolling was adjusted to make the average coefficient of friction 0.21. The temperature at the end of the finish hot rolling was kept a constant 900°C and the steel sheet finished to a thickness of 2.0 mm. After the end of the hot rolling, the steel sheet was quenched and then coiled at 500°C. The average coefficient of friction was found by calculating the coefficients from the actually measured forward slip ratio of the stands and finding the average of the same. Further, the strain rate of the final stand was made $290 s^{-1}$.

The hot rolled coil was annealed in a continuous annealing furnace at an annealing temperature of a constant 950°C and different annealing times. On the other hand, the hot rolled steel sheet was annealed by continuous annealing for 90 seconds and different annealing temperatures. The steel sheet was pickled, cold rolled to a thickness of 0.35 mm, then annealed at 900°C for 30 seconds. Epstein specimens were cut off and measured in magnetic properties.

The effect of the annealing time of the hot rolled steel sheet by the continuous annealing on the magnetic flux density of the product is shown in Fig. 7. As shown in Fig. 7, at an annealing time of less than 20 seconds, no effect of improvement of the magnetic flux density by the annealing of the hot rolled steel sheet is obtained, while with an annealing time of over 5 minutes, deep scale layer is produced in the surface of the steel sheet, pickling defects occur, and the surface layer of the steel sheet becomes remarkably rough. Therefore, in the present invention, the annealing time of the hot rolled steel sheet by the continuous annealing is made 20 seconds to 5 minutes. The preferred annealing time of the hot rolled sheet by the continuous annealing viewed from the effect of the annealing and of economy is 30 seconds to 3 minutes.

The effect of the annealing temperature of the hot rolled steel sheet by the continuous annealing on the magnetic flux density of the product is shown in Fig. 8. As shown in Fig. 8, when the annealing temperature is less than 850°C, no effect of improvement of the magnetic flux density by the annealing of the hot rolled steel sheet by continuous annealing is obtained, while if the annealing temperature is more than 1150°C, deep scale layer is produced and therefore pickling defects occur and the surface layer of the steel sheet becomes remarkably rough. Therefore, in the present invention, the annealing temperature of the hot rolled steel sheet by the continuous annealing is made 850°C to 1150°C. The preferred annealing temperature of the hot rolled steel sheet by the continuous annealing viewed from the effect of the annealing and of economy such as the pickling ability is 850°C to 1000°C.

In the present invention, the annealing of the hot rolled sheet may also be performed by box annealing. At this time, if the annealing temperature of the hot rolled steel sheet is less than 750°C, the annealing time required for improving the magnetic properties of the product becomes remarkably long, which is not economical. Further, if the annealing temperature is more than 850°C, a large amount of funds are required for the capital investment for the furnace and generating sticking of the coil during annealing. For the above reasons, when annealing the hot rolled steel sheet by box annealing, the lower limit of the annealing temperature is made 750°C and the upper limit is made 850°C. At this time, if the annealing time of the hot rolled steel sheet by box annealing is less than 5 minutes, the annealing temperature required for improving the magnetic properties of the product becomes remarkably high and the capital investment for the furnace itself becomes excessive and uneconomical, therefore the lower limit of the annealing time is not less than 5 minutes. Further, if the annealing time of the hot rolled steel sheet is over 30 hours, like when the annealing temperature is excessively high, the coil sticks, so the annealing time of the hot rolled steel sheet by box annealing is made less than 30 hours.

The hot rolled sheet annealed in this way may then be subjected to one cold rolling process and then finishing annealing or then subjected to a skin pass rolling process to make the final product.

The finishing annealing is performed by continuous annealing, as disclosed in Japanese Unexamined Patent Publication (Kokai) No. 61-213320, it is possible to perform the finishing annealing by first annealing for a short period of 5 seconds to 1 minute in a temperature range of 950°C to 1100°C and then holding the sheet for 10 seconds to 2 minutes at 800°C to 950°C.

<u>Self-Annealing Process</u>

Next, the following experiment was performed to investigate the effect of the average coefficient of friction between the hot rolling roll and steel sheet at the finish hot rolling on the magnetic properties of the product in the process of self annealing by the heat held by the hot rolling coil. Steel composition shown in Table 5 was melted and subjected to finish hot rolling.

The coefficient of friction at the finish hot rolling was changed from 0.1 or so to at least 0.3 by changing the content of the lubricant oil in the cooling water and the composition of the lubricant oil. The average coefficient of friction was found by calculating the coefficients from the actually measured forward slip ratio of the stands and finding the average of the same. The temperature of the end of the finish hot rolling was made a constant 1000°C, the sheet was finished to a thickness of 2.5 mm, coiled at 900°C, then immediately carried into the heat maintaining furnace and self annealed at 860°C for 1 hour. The strain rate of the final stand was made 300 s^{-1}.

The steel sheet was pickled, cold rolled to a thickness of 0.50 mm, then annealed for 45 seconds at 900°C in the case of the steel E and 980°C in the case of the steel F. Epstein specimens were cut out and measured in magnetic properties.

The dependency of the magnetic flux density of the product on the average coefficient of friction at the finish hot rolling is shown in Fig. 9. As the average coefficient of friction, the average of the actually measured values of the stands of the finish hot rolling mill was used. From Fig. 9, it is learned that the magnetic flux density of the product rises if the average coefficient of friction at the finish hot rolling is not more than 0.25.

As shown in the above experiment, the value of the coefficient of friction between the rolling roll of the finish hot rolling and the steel sheet should be not more than 0.25 in terms of the average value for all of the stands at the finish hat rolling. If above 0.25, the effect is not sufficient and the magnetic flux density of the product falls.

Table 5

Composition of Material Used						
	C	Si	Mn	S	sol-Al	N
Steel E	0.0019	2.15	0.12	0.0017	0.25	0.0018
Steel F	0.0018	3.02	0.11	0.0018	0.61	0.0015

When performing the finish hot rolling at a low friction rate or low friction rate and high strain rate as in the present invention, when the sheet bar is hot rolled by the finishing mill, rolling bite defects of the sheet bar occur, slip occurs between the roll and the steel sheet during the finish hot rolling, the lifetime of the rolling roll is remarkably shortened, and deep rolling defects are caused in the surface layer of the steel sheet. As a method to solve these problems in finish hot rolling at such a low friction rate and stabilize the operation, it is particularly effective to weld the sheet bar after rough rolling to the preceding sheet bar before the finish hot rolling and continuously supply the sheet bars to the finish hot rolling.

When the coiling temperature of the coil at the self annealing is less than 750°C, the improvement of the magnetic properties is insufficient, so the temperature is made at least 750°C. On the other hand, if 1000°C is exceeded, coiling deviations of the coil easily occur and oxidation of the surface layer of the steel sheet becomes severe.

If the self annealing is less than 5 minutes, the improvement of the magnetic properties is insufficient, so self annealing is made at least 5 minutes. Further, if the self annealing is over 5 hours, the oxidation of the steel sheet becomes severe and pickling defects easily occur, so the self annealing is made more than 5 hours. The preferred self annealing time viewed from the effect of the annealing and economy is 30 minutes to 120 minutes.

In the present invention, to prevent oxidation of the coil during the self annealing, the self annealing may be performed in a reducing atmosphere containing hydrogen or an inert gas atmosphere of nitrogen, argon, etc. or under reduced pressure.

The hot rolled steel sheet subjected to self annealing in this way is subjected to one or two or more cold rolling processes including annealing, then finishing annealing or then further a skin pass rolling process to produce the final product.

The amount of the lubricant oil mixed in with the cooling water for cooling the roll at the finish hot rolling is 0.5% to 20% by percent volume. A surfactant may be added if necessary to prevent the lubricant oil and cooling water from separating. If the amount of the lubricant oil in the cooling water is less than 0.5%, the effect is not obtained, while if over 20%, the effect becomes saturated and is uneconomical, so the amount is made less than 20%.

The hot rolled steel sheet obtained in this way is subjected to one cold rolling process and continuous annealing to make the product. Further, it may be subjected to an additional skin pass rolling process to make the product. If the reduction ratio at the skin pass rolling is less than 2%, the effect is not obtained, while if the reduction ratio is over 20%, the magnetic properties deteriorate, so the reduction ratio must be limit to 2% to 20%.

Process of Providing Certain Period of Non-Coolant After Hot Rolling

Next, the following experiment was performed to investigate the effect of the average coefficient of friction between the hot rolling roll and the steel sheet at the finish hot rolling on the magnetic properties of the product. Steel G of the composition shown in Table 6 was melted and then subjected to finish hot rolling.

The coefficient of friction at the finish hot rolling was changed from 0.1 or so to at least 0.3 by changing the content of the lubricant oil in the cooling water and the composition of the lubricant oil. The average coefficient of friction was found by calculating the coefficients from the actually measured forward slip ratio of the stands and finding the average of the same. The temperature at the end of the finish hot rolling was made a constant 1050°C and, according to formula (1), the non-coolant time was made 3.5 seconds, then the steel sheet was cooled and coiled at 680°C. The strain rate at the final stand in the finish rolling was made 290 s^{-1}.

The steel sheet was then pickled and cold rolled to a thickness of 0.50 mm, then annealed for 30 seconds at 900°C, then Epstein specimens were cut out and measured for magnetic properties.

The dependency of the magnetic flux density of the product on the average coefficient of friction at the finish hot rolling is shown in Fig. 10. As the average coefficient of friction, the average of the actually measured values of the stands of the finish hot rolling mill was used. From Fig. 10, it was learned that the magnetic flux density of the product rises if the average coefficient of friction at the finish hot rolling is less than 0.25.

As shown from the above experiments, the value of the coefficient of friction between the rolling roll and steel sheet at the finish hot rolling should be not more than 0.25 in terms of the average value of all of the stands in the finish hot rolling. If over 0.25, the effect is insufficient and the magnetic flux density of the product falls. No upper limit is particularly set for the coefficient of friction, but if the value is excessively small, slip occurs during the rolling and stable rolling operation is no longer possible, so the value is preferably at least 0.05.

Table 6

Composition of Material Used						
	C	Si	Mn	S	sol-Al	N
Steel E	0.0017	2.50	0.22	0.0016	0.28	0.0019

When performing the finish hot rolling at a low friction rate or low friction rate and high strain rate as in the present invention, at the time the sheet bar is hot rolled by the finishing mill, rolling bite defects of the sheet bar occur, slip occurs between the roll and the steel sheet during the finish hot rolling, the lifetime of the rolling roll is remarkably shortened, and deep rolling defects are caused in the surface layer of the steel sheet. As a method to solve these problems in finish hot rolling at such a low friction rate and to stabilize the operation, it is particularly effective to weld the sheet bar after rough rolling to the preceding sheet bar before the finish hot rolling and continuously supply the sheet bars to the finish hot rolling.

The coiling temperature of the coil is not defined, but to prevent the occurrence of an excessive oxidation layer on the surface of the steel sheet and deterioration of the pickling ability after the end of the high temperature hot rolling, the coil it preferably coiled at under 750°C.

The time set for non-coolant after the end of the hot rolling is determined as follows in relation to the temperature T (°C) at the end of the hot rolling. The inventors studied the relationship between the temperature T (°C) at the end of the hot rolling in finish hot rolling, the time t (seconds) until the start of the coolant spray after the end of the hot rolling, and the magnetic properties in detail and as a result found that it was possible to set excellent conditions satisfying the pickling ability, rolling speed, and magnetic properties in the range determined by:

$$950 \leq T(°C) \leq 1150 \qquad \text{Formula (1)}$$

$$9.6 - 8 \times 10^{-3}T \leq t\,(\text{sec}) \leq 15.6 - 8 \times 10^{-3}T \qquad \text{Formula (2)}$$

Further, if the time until the start of coolant spray after the end of the hot rolling exceeds the time set by formula (2), the time for cooling the steel sheet becomes insufficient and it is necessary to coil at a high temperature or lower the rolling speed to enable sufficient cooling or else the productivity will deteriorate. Coiling at a high temperature is not preferable since it causes problems such as occurrence of coiling deviations and deterioration of the pickling ability. Therefore, the non-coolant time was made not more than the upper limit time set by formula (2). If the non-coolant time becomes shorter than the time set by formula (2), the improvement of the magnetic properties becomes insufficient. In the same way as when the temperature T (°C) at the end of the hot rolling is lower than 950°C, the improvement of the magnetic properties is insufficient. Further, to make the temperature at the end of the hot rolling over 1150°C, in a normal hot rolling process having rough rolling and finish rolling steps, the slab heating temperature would have to be made remarkably high, precipitates re-dissolve during the slab heating precipitate finely during the hot rolling, and the magnetic properties are made to remarkably deteriorate, so the temperature at the end of the hot rolling is made not more than 1150°C.

In the present invention, the steel sheet may be subjected to one cold rolling process and then a finishing annealing process or a further skin pass rolling process to make the final product.

When adding a skin pass rolling process, the effect is not obtained if the skin pass rolling rate is less than 2%. If over 20%, the magnetic properties deteriorate, so the rate is made 2% to 20%.

Examples

Next, examples of the present invention will be explained.

〈Example 1〉

A slab for non-oriented electrical steel sheet having the composition shown in Table 7 was heated by an ordinary method, was finished to a sheet bar of a thickness of 35 mm by a roughing mill, then was finished to 1.8 mm by a finish hot rolling mill. Lubricant oil was mixed with the cooling water of the finish hot rolling mill. The amount mixed was changed to 0.2% to 10% by percent volume to adjust the coefficient of friction. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forward slip ratio in the stands and then taking the average of the same. The hot rolling finishing temperature was made 860°C.

Next, the steel sheet was pickled and finished to a thickness of 0.50 mm by cold rolling. This was then annealed in a continuous annealing furnace at 940°C for 30 seconds. Next, Epstein specimens were cut out and measured for magnetic properties. Table 8 shows the results of measurement of the magnetic properties for the present invention and comparative examples together.

If the average coefficient of friction at the finish hot rolling is reduced in this way, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Table 7

Composition of Material Used					
C	Si	Mn	S	sol-Al	N
0.0011	2.10	0.20	0.0014	0.20	0.0011

Table 8

Results of Measurement of Magnetism			
	Average coefficient of friction at finish rolling	Magnetic flux density B50 (T)	Iron loss W15/50 (W/kg)
Invention	0.16	1.708	3.42
Invention	0.20	1.707	3.46
Comp. Ex.	0.28	1.659	3.76
Comp. Ex.	0.35	1.655	3.79

〈Example 2〉

A slab for non-oriented electrical steel sheet having the composition shown in Table 9 was heated by an ordinary method, was finished to a sheet bar of a thickness of 36 mm by a roughing mill, then was finished to 2.3 mm by a finish hot rolling mill. Lubricant oil was mixed with the cooling water of the finish hot rolling mill. The amount mixed was changed to 0.2% to 7% by percent volume to adjust the coefficient of friction. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forward slip ratio in the stands and then taking the average of the same. The temperature at the end of the finish hot rolling was made 950°C. The sheet was then immediately quenched and coiled at 600°C. The obtained hot rolled sheet was annealed by a continuous annealing furnace at 930°C for 2 minutes.

Next, the steel sheet was pickled and finished to a thickness of 0.50 mm by cold rolling. This was then annealed in a continuous annealing furnace at 900°C for 30 seconds. Next, Epstein specimens were cut out and measured for magnetic properties. Table 10 shows the results of measurement of the magnetic properties for the present invention and comparative examples together.

If the average coefficient of friction at the finish hot rolling is reduced in this way to less than 0.25, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Table 9

Composition of Material Used					
C	Si	Mn	S	sol-Al	N
0.0015	2.51	0.20	0.0013	0.24	0.0011

Table 10

Results of Measurement of Magnetism			
	Average coefficient of friction at finish rolling	Magnetic flux density B50 (T)	Iron loss W15/50 (W/kg)
Invention	0.17	1.732	2.91
Invention	0.21	1.731	2.95
Comp. Ex.	0.28	1.710	3.11
Comp. Ex.	0.35	1.708	3.12

〈Example 3〉

A slab for non-oriented electrical sheet having the composition shown in Table 11 was heated by an ordinary method, was finished to a sheet bar of a thickness of 30 mm by a roughing mill, then was finished to 1.0 mm by a finish hot rolling mill. Lubricant oil was mixed with the cooling water of the finish hot rolling mill. The amount mixed was changed to adjust the coefficient of friction. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forward slip ratio in the stands and then taking the average of the same. The hot rolling finishing temperature was made 860°C.

Next, the steel sheet was pickled and finished to a thickness of 0.50 mm by cold rolling. This was then annealed in a continuous annealing furnace at 940°C for 30 seconds. Next, Epstein specimens were cut out and measured for magnetic properties. Table 12 shows the results of measurement of the magnetic properties for the present invention and comparative examples together.

If the average coefficient of friction at the finish hot rolling is reduced in this way, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Further, it was learned from Table 12 that by rolling the steel sheet at a low coefficient of friction and reducing the cold rolling reduction ratio to about 50% as in the examples, it was possible to improve the magnetic flux density of the product remarkably.

Table 11

Composition of Material Used					
C	Si	Mn	S	sol-Al	N
0.0016	2.00	0.18	0.0015	0.25	0.0016

Table 12

Results of Measurement of Magnetism			
	Average coefficient of friction at finish rolling	Magnetic flux density B50 (T)	Iron loss W15/50 (W/kg)
Invention	0.11	1.710	3.41
Invention	0.16	1.710	3.42
Invention	0.20	1.708	3.45
Comp. Ex.	0.28	1.660	3.75
Comp. Ex.	0.35	1.655	3.78

〈Example 4〉

A slab for non-oriented electrical steel sheet having the composition shown in Table 13 was heated by an ordinary method, was finished to a sheet bar of a thickness of 35 mm by a roughing mill, then was finished to 2.5 mm by a finish hot rolling mill. 5% by percent volume of lubricant oil was mixed with the cooling water of the finish hot rolling mill to adjust the average coefficient of friction of the stands to 0.19. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forward slip ratio in the stands and then taking the average of the same. Further, to prevent the occurrence of slip between the steel sheet and the work roll during the finish hot rolling and the formation of defects on the surface of the steel sheet, the rough rolled sheet bar was welded to the preceding sheet bar and the finish hot rolling continuously performed. At this time, the hot rolling finishing temperature was made 860°C. The sheet was immediately water cooled and coiled at 650°C. The pass schedule was adjusted so that the maximum strain rate was obtained at the final stand. The strain rate of the final stand wag changed in the range between 131 s^{-1} to 322 s^{-1}.

Next, the steel sheet was pickled and finished to a thickness of 0.50 mm by cold rolling. This was then annealed in a continuous annealing furnace at 900°C for 30 seconds. Next, Epstein specimens were cut out and measured for magnetic properties. Table 14 shows the results of measurement of the magnetic properties for the present invention and comparative examples together.

By reducing the average coefficient of friction at the finish hot rolling in this way and controlling the strain rate for at least one pass to not less than 150 s^{-1}, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Table 13

Composition of Material Used					
C	Si	Mn	S	sol-Al	N
0.0015	1.60	0.12	0.0014	0.25	0.0016

Table 14

Results of Measurement of Magnetism				
	Strain rate of final stand (S^{-1})	Magnetic flux density B50 (T)	Iron loss W15/50 (W/kg)
Comp. Ex.	131	1.708	4.49
Invention	175	1.728	4.13
Invention	232	1.731	4.01
Invention	265	1.735	4.00
Invention	322	1.736	3.99

〈Example 5〉

A slab for non-oriented electrical sheet having the composition shown in Table 15 was heated by an ordinary method, was finished to a sheet bar of a thickness of 40 mm by a roughing mill, then was finished to 2.0 mm by a finish hot rolling mill. Lubricant oil was mixed with the cooling water of the finish hot rolling mill in an emulsion state. The amount mixed was changed to adjust the average coefficient of friction. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forward slip ratio in the stands and then taking the average of the same. The strain rate of the final stand was made 305 s^{-1}.

Further, to prevent the occurrence of slip between the steel sheet and the work roll during the finish hot rolling and the formation of defects on the surface of the steel sheet, after the rough rolling, the rear end of the preceding sheet bar was aligned with the front end of the succeeding sheet bar, a force was applied pressing the aligned portion, and the aligned portion was joined by laser welding and the finish hot rolling continuously performed. At this time, the hot rolling finishing temperature was made 860°C.

Next, the steel sheet was pickled and finished to a thickness of 0.35 mm by cold rolling. This was then annealed in a continuous annealing furnace at 900°C for 30 seconds. Next, Epstein specimens were cut out and measured for magnetic properties. Table 16 shows the results of measurement of the magnetic properties for the present invention and comparative examples together.

By reducing the average coefficient of friction at finish hot rolling in this way, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Table 15

Composition of Material Used					
C	Si	Mn	S	sol-Al	N
0.0017	2.95	0.11	0.0017	0.60	0.0015

Table 16

Results of Measurement of Magnetism			
	Average coefficient of friction at finish rolling	Magnetic flux density B50 (T)	Iron loss W15/50 (W/kg)
Invention	0.12	1.661	2.38
Invention	0.14	1.660	2.38
Invention	0.21	1.659	2.39
Comp. Ex.	0.28	1.639	2.54
Comp. Ex.	0.34	1.637	2.55

〈Example 6〉

A slab for non-oriented electrical steel sheet having the composition shown in Table 17 was heated by an ordinary method, was finished to a sheet bar of a thickness of 50 mm by a roughing mill, then was finished to 2.5 mm by a finish hot rolling mill. 2% to 11% by percent volume of lubricant oil was mixed with the cooling water of the finish hot rolling mill in accordance with the change of the strain rate to adjust the average coefficient of friction of the stands to 0.20. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forward slip ratio in the stands and then taking the average of the same. Further, to prevent the occurrence of slip between the steel sheet and the work roll during the finish hot rolling and the formation of defects on the surface of the steel sheet, after the rough rolling, the rear end of the preceding sheet bar was aligned with the front end of the succeeding sheet bar, a force was applied pressing the aligned portion, and the aligned portion was joined by laser welding and the finish hot rolling continuously performed. At this time, the hot rolling finishing temperature was made 860°C. The steel sheet was immediately water cooled and coiled at 650°C.

Next, the steel sheet was pickled and finished to a thickness of 0.50 mm by cold rolling. This was then annealed in a continuous annealing furnace at 940°C for 30 seconds. Next, Epstein specimens were cut out and measured for magnetic properties. Table 18 shows the results of measurement of the magnetic properties for the present invention and comparative examples together.

If the strain rate of the final pass at the time of the finish hot rolling is raised to at least 150 s^{-1} in this way, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Table 17

Composition of Material Used					
C	Si	Mn	S	Al	N
0.0018	2.06	0.11	0.0017	0.20	0.0016

Table 18

Results of Measurement of Magnetism			
	Strain rate of final stand (S^{-1})	Magnetic flux density B50 (T)	Iron loss W15/50 (W/kg)
Comp. Ex.	133	1.660	3.76
Invention	172	1.682	3.59
Invention	210	1.690	3.57
Invention	253	1.694	3.52
Invention	310	1.695	3.50

〈Example 7〉

A slab for non-oriented electrical steel sheet having the composition shown in Table 19 was heated by an ordinary method, was finished to a sheet rough bar of a thickness of 40 mm by a roughing mill, then wan finished to 2.0 mm by a finish hot rolling mill. Lubricant oil was mixed with the cooling water of the finish hot rolling mill. The amount mixed was changed to adjust the average coefficient of friction. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forward slip ratio in the stands and then taking the average of the same. At this time, the temperature at the end of the finish hot rolling was made 900°C. The strain rate of the final stand was made 320 s^{-1}. The obtained hot rolled steel sheet was then annealed in a continuous annealing furnace at 900°C for 2 minutes.

Next, the steel sheet was pickled and finished to a thickness of 0.50 mm by cold rolling. This was then annealed in a continuous annealing furnace at 900°C for 30 seconds. Next, Epstein specimens were cut out and measured for magnetic properties.

Further, the material shown in Table 19 was processed under the same conditions up to the pickling, then was cold rolled to a finished sheet thickness of 0.55 mm. This was then annealed in a continuous annealing furnace at 900°C for 30 seconds. Next, this was subjected to skin pass rolling to finish it to 0.50 mm. Epstein specimens were cut out, annealed at 750°C for 2 hours to relieve the stress, and measured for magnetic properties.

Table 20 shows the results of measurement of the magnetic properties for the present invention and comparative examples together.

If the average coefficient of friction at the time of the finish hot rolling is reduced to less than 0.25, the strain rate is made at least 150 s^{-1} at least at one pass, and the annealing conditions of the hot rolled steel sheet suitably controlled, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Table 19

Composition of Material Used					
C	Si	Mn	S	sol-Al	N
0.0019	2.00	0.19	0.0017	0.24	0.0019

Table 20

Results of Measurement of Magnetism				
	Skin pass rolling	Average coefficient of friction at finish rolling	Magnetic flux density B50 (T)	Iron loss W15/50 (W/kg)
Invention	None	0.11	1.740	3.31
Invention	None	0.16	1.739	3.32
Invention	None	0.20	1.739	3.32
Comp. Ex.	None	0.27	1.715	3.45
Comp. Ex.	None	0.35	1.714	3.46
Invention	Yes	0.11	1.722	3.02
Invention	Yes	0.16	1.721	3.04
Invention	Yes	0.20	1.720	3.05
Comp. Ex.	Yes	0.27	1.700	3.21
Comp. Ex.	Yes	0.35	1.699	3.25

〈Example 8〉

A slab for non-oriented electrical sheet having the composition shown in Table 21 was heated by an ordinary method, was finished to a sheet bar of a thickness of 40 mm by a roughing mill, then was finished to 1.8 mm by a finish hot rolling mill. Lubricant oil was mixed with the cooling water of the finish hot rolling mill in an emulsion state. The amount mixed was changed to adjust the average coefficient of friction. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forward slip ratio in the stands and then taking the average of the same. The strain rate of the final stand was made 315 s^{-1}. Further, to prevent the occurrence of slip between the steel sheet and the work roll during the finish hot rolling and the formation of defects on the surface of the steel sheet, the rough rolled sheet bar was welded to the preceding sheet bar and the finish hot rolling continuously performed. The hot rolling finishing temperature was made 900°C. After the end of the rolling, the steel sheet was immediately cooled and coiled at 500°C. The obtained hot rolled steel sheet was then annealed in a continuous annealing furnace at 950°C for 2 minutes.

Next, the sheet was pickled and finished to a thickness of 0.35 mm by cold rolling. This was then held in a continuous annealing furnace at 1050°C for 10 seconds in a front stage and was held at 900°C for 30 seconds in a rear stage. Next, Epstein specimens were cut out and measured for magnetic properties. Table 22 shows the results of measurement of the magnetic properties for the present invention and comparative examples together.

As shown in Table 22, if the average coefficient of friction at the time of the finish hot rolling is reduced to less than 0.25, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

If the average coefficient of friction at the time of the finish hot rolling is reduced to less than 0.25, the strain rate is made at least 150 s^{-1} at least at one pass, and the annealing conditions of the hot rolled sheet suitably controlled, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Table 21

Composition of Material Used					
C	Si	Mn	S	sol-Al	N
0.0011	3.01	0.12	0.0011	0.50	0.0014

Table 22

Results of Measurement of Magnetism			
	Average coefficient of friction at finish rolling	Magnetic flux density B50 (T)	Iron loss W15/50 (W/kg)
Invention	0.11	1.691	2.31
Invention	0.16	1.690	2.33
Invention	0.20	1.690	2.34
Comp. Ex.	0.27	1.671	2.51
Comp. Ex.	0.34	1.670	2.53

〈Example 9〉

A slab for non-oriented electrical steel sheet having the composition shown in Table 23 was heated by an ordinary method, was finished to a sheet bar of a thickness of 40 mm by a roughing mill, then was finished to 1.8 mm by a finish hot rolling mill. Lubricant oil was mixed with the cooling water of the finish hot rolling mill in an emulsion state. The amount mixed was adjusted to 4% by percent volume to make the average coefficient of friction 0.20. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forward slip ratio in the stands and then taking the average of the same. The strain rate of the final stand was made 310 s^{-1}. The hot rolling finishing temperature was made 900°C. After the end of the rolling, the sheet was immediately cooled and coiled at 500°C. The obtained hot rolled steel sheet was then annealed in a continuous annealing furnace at different annealing temperatures and annealing times.

Next, the sheet was pickled and finished to a thickness of 0.35 mm by cold rolling. This was then annealed in a continuous annealing furnace at 900°C for 30 seconds. Next, Epstein specimens were cut out and measured for magnetic properties. Table 22 shows the annealing conditions of the hot rolled steel sheet and the results of measurement of the magnetic properties together.

As shown in Table 24, if the annealing temperature of the hot rolled steel sheet is 850°C to 1150°C, it is possible to obtain a non-oriented electrical steel sheet with superior properties. If the annealing temperature of the hot rolled steel sheet is less than 850°C, the improvement of the magnetic properties is insufficient, while if it is over 1150°C, pickling defects occur, the surface properties of the product deteriorate, and the iron loss deteriorates.

Further, it was learned that if the annealing time of the hot rolling sheet by the continuous annealing is from 20 seconds to 5 minutes, superior magnetic properties are obtained. When the annealing time of the hot rolled steel sheet by the continuous annealing is more than 5 minutes, pickling defects occur and the iron loss conversely deteriorates.

If the average friction coefficient at the time of the finish hot rolling is reduced to less than 0.25, the strain rate is made at least 150 s^{-1} at least at one pass, and the annealing conditions of the hot rolled steel sheet suitably controlled, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Table 23

Composition of Material Used						
C	Si	Mn	S	sol-Al	N	O
0.0019	2.00	0.19	0.0017	0.24	0.0019	0.005

Table 24

Results of Measurement of Magnetism					
	Annealing temp. of hot rolled sheet (°C)	Annealing time of hot rolled sheet (sec.)	Magnetic flux density B50 (T)	Iron loss W15/50 (W/kg)	Remarks
Comp. Ex.	800	120	1.670	2.58	
Invention	870	120	1.689	2.37	
Invention	950	120	1.692	2.31	
Invention	1050	120	1.690	2.33	
Comp. Ex.	1200	120	1.688	2.42	Pickling defect
Comp. Ex.	900	10	1.645	2.51	
Invention	900	30	1.682	2.35	
Invention	900	90	1.689	2.34	
Invention	900	180	1.690	2.31	
Comp. Ex.	900	360	1.688	2.43	Pickling defect

〈Example 10〉

A slab for non-oriented electrical steel sheet having the composition shown in Table 25 was heated to 1200°C by an ordinary method, was finished to a sheet bar of a thickness of 30 mm by a roughing mill, then was finished to 1.8 mm by a finish hot rolling mill. Lubricant oil was mixed with the cooling water of the finish hot rolling mill in an emulsion state. The amount mixed was adjusted to change the average coefficient of friction. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forwarding rates in the stands and then taking the average of the same. The maximum strain rate of the final stand was made 175 s^{-1}. The hot rolling finishing temperature was made 1000°C. After the end of the rolling, the steel sheet was immediately cooled and coiled at 650°C. Next, the steel sheet was rolled at a temperature of 300°C to 0.85 mm, then further process annealed at 980°C for 30 seconds, then finished to 0.25 mm by warm rolling of 200°C and pickled. This was then held and annealed in a continuous annealing furnace at 850°C for 30 seconds, then finished to 0.23 mm by 8% skin pass rolling. Next, Epstein specimens were cut out, annealed at 800°C for 2 hours to relieve the stress, then measured for magnetic properties. Table 26 shows the results of measurement of the magnetic properties for the present invention and the comparative examples together.

As shown in Table 26, if the average coefficient of friction at the time of the finish hot rolling is reduced to less than 0.25, the strain rate is made at least 150 s^{-1} at least at one pass, and the annealing conditions of the hot rolled steel sheet suitably controlled, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Table 25

Composition of Material Used						
C	Si	Mn	S	P	N	sol-Al
0.0015	6.51	0.15	0.0010	0.007	0.0015	0.025

Table 26

Results of Measurement of Magnetism				
	Average coefficient of friction at finish rolling	Magnetic flux density B50 (T)	Iron loss W10/50 (W/kg)	Iron loss W15/400 (W/kg)
Invention	0.19	1.422	0.53	6.95
Invention	0.22	1.420	0.55	7.05
Comp. Ex.	0.29	1.400	0.63	8.21
Comp. Ex.	0.34	1.399	0.65	8.30

〈Example 11〉

A slab for non-oriented electrical steel sheet having the composition shown in Table 27 was heated by an ordinary method, was finished to a sheet bar of a thickness of 40 mm by a roughing mill, then was finished to 2.0 mm by a finish hot rolling mill. Lubricant oil was mixed with the cooling water of the finish hot rolling mill in an emulsion state. The amount mixed was changed to 0.2% by percent volume to adjust the average coefficient of friction. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forward slip ratio in the stands and then taking the average of the same. At this time, the hot rolling finishing temperature was made 900°C. The strain rate of the final stand was made 315 s^{-1}. The obtained hot rolled steel sheet was annealed in a box annealing furnace at 800°C for 5 hours.

The sheet was then pickled and finished to 0.50 mm by cold rolling. This was annealed in a continuous annealing furnace at 900°C for 30 seconds in the case of the steel H and at 980°C for 30 seconds in the case of the steel I. Next, Epstein specimens were cut out, then measured for magnetic properties. Table 28 shows the results of measurement of the magnetic properties for the present invention and the comparative examples together.

If the average coefficient of friction at the finish hot rolling is reduced to less than 0.25 and the strain rate is made at least 150 s^{-1} at least at one pass, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Table 27

Composition of Material Used						
	C	Si	Mn	S	sol-Al	N
Steel H	0.0018	2.02	0.12	0.0016	0.25	0.0018
Steel I	0.0017	3.00	0.13	0.0018	0.45	0.0015

Table 28

Results of Measurement of Magnetism			
Steel H	Average coefficient of friction at finish rolling	Magnetic flux density B50	Iron loss W15/50 (T) (W/kg)
Invention	0.15	1.743	3.28
Invention	0.19	1.742	3.29
Invention	0.22	1.740	3.30
Comp. Ex.	0.29	1.720	3.41
Comp. Ex.	0.35	1.719	3.42
Steel I	Average coefficient of friction at finish rolling	Magnetic flux density B50 (T)	Watt loss W15/50 (W/kg)
Invention	0.16	1.698	2.60
Invention	0.19	1.697	2.61
Invention	0.23	1.697	2.62
Comp. Ex.	0.29	1.677	2.81
Comp. Ex.	0.34	1.676	2.88

〈Example 12〉

A slab for non-oriented electrical steel sheet having the composition shown in Table 29 was heated by an ordinary method, was finished to a sheet bar of a thickness of 50 mm by a roughing mill, then was finished to 2.5 mm by a finish hot rolling mill. Lubricant oil was mixed with the cooling water of the finish hot rolling mill. The amount mixed was changed to 0.2% to 8% by percent volume to adjust the average coefficient of friction. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forward slip ratio in the stands and then taking the average of the same. The strain rate of the final stand was made 320 s^{-1}. At this time, the temperature at the end of the finish hot rolling was made 1000°C. The steel sheet was coiled at 875°C, the coil was inserted into a heat maintaining furnace, and self annealing was performed at 850°C for 1 hour.

This was then pickled and finished to 0.50 mm by cold rolling. This was annealed in a continuous annealing furnace at 900°C for 45 seconds. Next, Epstein specimens were cut out, then measured for magnetic properties. Table 30 shows the results of measurement of the magnetic properties for the present invention and the comparative examples together.

If the average coefficient of friction at the time of the finish hot rolling is reduced to less than 0.25, the strain rate is made at least 150 s^{-1} at least at one pass, and suitable self annealing conditions are set, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Table 29

Composition of Material Used					
C	Si	Mn	S	sol-Al	N
0.0022	2.10	0.12	0.0019	0.22	0.0021

Table 30

Results of Measurement of Magnetism			
	Average coefficient of friction at finish rolling	Magnetic flux density B50 (T)	Iron loss W15/50 (W/kg)
Invention	0.16	1.722	3.38
Invention	0.20	1.720	3.41
Comp. Ex.	0.27	1.700	3.52
Comp. Ex.	0.35	1.699	3.55

⟨Example 13⟩

A slab for non-oriented electrical steel sheet having the composition shown in Table 31 was heated by an ordinary method, was finished to a sheet bar of a thickness of 55 mm by a roughing mill, then was finished to 2.0 mm by a finish hot rolling mill. Lubricant oil was mixed with the cooling water of the finish hot rolling mill. The amount mixed wax adjusted to change the average coefficient of friction. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forward slip ratio in the stands and then taking the average of the same. The strain rate of the final stand was made 310 s^{-1}. Further, to prevent the occurrence of slip between the steel sheet and the work roll during the finish hot rolling and the formation of defects on the surface of the steel sheet, the rough rolled steel sheet bar was welded to the preceding sheet bar and the finish hot rolling continuously performed. The hot rolling finishing temperature was made 990°C. The sheet was coiled at 880°C, then the coil was immediately inserted into a heat maintaining furnace and self annealed at 850°C for 1 hour.

Next, the steel sheet was pickled and finished to a thickness of 0.35 mm by cold rolling. This was then annealed in a continuous annealing furnace at 1050°C for 30 seconds. Next, Epstein specimens were cut out and measured for magnetic properties. Table 32 shows the results of measurement of the magnetic properties for the present invention and comparative examples together.

As shown in Table 32, if the average coefficient of friction at the finish hot rolling is reduced to less than 0.25, the strain rate is made at least 150 s^{-1} at least at one pass, and suitable self annealing conditions are set, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Table 31

Composition of Material Used					
C	Si	Mn	S	sol-Al	N
0.0013	3.05	0.11	0.0017	0.40	0.0018

Table 32

Results of Measurement of Magnetism			
	Average coefficient of friction at finish rolling	Magnetic flux density B50 (T)	Iron loss W15/50 (W/kg)
Invention	0.19	1.678	2.44
Invention	0.22	1.677	2.46
Comp. Ex.	0.27	1.663	2.62
Comp. Ex.	0.34	1.662	2.65

〈Example 14〉

A slab for non-oriented electrical steel sheet having the composition shown in Table 33 was heated by an ordinary method, was finished to a sheet bar of a thickness of 50 mm by a roughing mill, then was finished to 2.5 mm by a finish hot rolling mill. Lubricant oil was mixed with the cooling water of the finish hot rolling mill. The amount mixed was adjusted to 2.5% by percent volume to make the average coefficient of friction 0.21. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forward slip ratio in the stands and then taking the average of the same. The coil after the end of the hot rolling was self annealed at the conditions shown in Table 34.

Next, the steel sheet was pickled and finished to a thickness of 0.35 mm by cold rolling. This was then annealed in a continuous annealing furnace at 980°C for 45 seconds. Next, Epstein specimens were cut out and measured for magnetic properties. Table 34 shows the self annealing conditions and the results of measurement of the magnetic properties together.

As shown in Table 34, if the self annealing temperature is from 750°C to 1000°C, it is possible to obtain a non-oriented electrical steel sheet with superior properties. In this way, if the self annealing temperature is less than 750°C, the improvement of the magnetic properties is insufficient, while if the coiling temperature of the coil is raised to over 1000°C, coiling deviations occur, therefore self annealing is impossible.

Further, it was learned that if the self annealing time is from 5 minutes to 5 hours, superior magnetic properties are obtained. If the annealing time of the hot rolled steel sheet by the self annealing is more than 5 hours, pickling defects occur and the watt loss conversely deteriorates.

In this way, if the average coefficient of friction at the time of the finish hot rolling is reduced to less than 0.25 and suitable self annealing conditions are set, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Table 33

Composition of Material Used						
C	Si	Mn	S	sol-Al	N	O
0.0015	3.01	0.12	0.0018	0.61	0.0019	0.0005

Table 34

Results of Measurement of Magnetism						
	Coiling temp. (°C)	Self annealing temp. (°C)	Self annealing time (min)	Magnetic flux density B50 (T)	Iron loss W15/50 (W/kg)	Remarks
Comp. Ex.	730	700	60	1.662	2.69	
Invention	830	800	60	1.676	2.49	
Invention	870	850	60	1.681	2.43	
Invention	920	900	60	1.680	2.41	
Comp. Ex.	880	850	3	1.644	2.75	
Invention	880	850	30	1.679	2.46	
Invention	880	850	60	1.681	2.45	
Invention	880	850	90	1.682	2.42	
Comp. Ex.	880	850	400	1.678	2.57	Pickling defect

〈Example 15〉

A slab for non-oriented electrical steel sheet having the composition shown in Table 35 was heated by an ordinary method, was finished to a sheet bar of a thickness of 50 mm by a roughing mill, then was finished to 2.5 mm by a finish hot rolling mill. Lubricant oil was mixed with the cooling water of the finish hot rolling mill. The amount mixed was changed to 0.2% to 12% by percent volume to adjust the average coefficient of friction. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forwarding rates in the stands and then taking the average of the same. The temperature at the end of the finish hot rolling was made 950°C and the strain rate at the final stand was made 310 s^{-1}. The steel sheet was coiled at 850°C, then immediately inserted into a heat maintaining furnace and self annealed at 850°C for 1 hour.

Next, the steel sheet was pickled and finished to a thickness of 0.50 mm by cold rolling. This was then annealed in a continuous annealing furnace at 900°C for 30 seconds. Next, Epstein specimens were cut out and measured for magnetic properties. Table 36 shows the results of measurement of the magnetic properties for the present invention and comparative examples together.

In this way, if the average coefficient of friction at the time of the finish hot rolling is reduced to less than 0.25, the strain rate is made at least 150 s^{-1} at least at one pass, and suitable self annealing conditions are set, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Table 35

Composition of Material Used					
C	Si	Mn	S	sol-Al	N
0.0019	2.50	0.20	0.0014	0.25	0.0017

Table 36

Results of Measurement of Magnetism			
	Average coefficient of friction at finish rolling	Magnetic flux density B50 (T)	Iron loss W15/50 (W/kg)
Invention	0.16	1.722	3.04
Invention	0.22	1.721	3.05
Comp. Ex.	0.27	1.700	3.21
Comp. Ex.	0.35	1.699	3.22

⟨Example 16⟩

A slab for non-oriented electrical steel sheet having the composition shown in Table 37 was heated by an ordinary method, was finished to a sheet bar of a thickness of 50 mm by a roughing mill, then was finished to 2.5 mm by a finish hot rolling mill. Lubricant oil was mixed with the cooling water of the finish hot rolling mill in an emulsion state. The amount mixed was changed to 0.2% to 4% by percent volume to adjust the average coefficient of friction. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forward slip ratio in the stands and then taking the average of the same. The strain rate at the final stand was made 320 s^{-1}. At this time, the temperature at the end of the finish hot rolling was made 1020°C, the non-coolant time was made 3.5 seconds, and the sheet was coiled at 640°C.

Next, the steel sheet was pickled and finished to a thickness of 0.50 mm by cold rolling. This was then annealed in a continuous annealing furnace at 900°C for 30 seconds. Next, Epstein specimens were cut out and measured for magnetic properties. Table 38 shows the results of measurement of the magnetic properties for the present invention and comparative examples together.

In this way, if the average coefficient of friction at the time of the finish hot rolling is reduced to less than 0.25, the strain rate is made at least 150 s^{-1} at least at one pass, and suitable self annealing conditions are set, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Table 37

Composition of Material Used					
C	Si	Mn	S	sol-Al	N
0.0019	2.05	0.13	0.0017	0.23	0.0018

Table 38

Results of Measurement of Magnetism			
	Average coefficient of friction at finish rolling	Magnetic flux density B50 (T)	Iron loss W15/50 (W/kg)
Invention	0.19	1.721	3.08
Invention	0.22	1.719	3.10
Comp. Ex.	0.27	1.703	3.33
Comp. Ex.	0.35	1.702	3.36

〈Example 17〉

A slab for non-oriented electrical steel sheet having the composition shown in Table 39 was heated by an ordinary method, was finished to a sheet bar of a thickness of 55 mm by a roughing mill, then was finished to 2.5 mm by a finish hot rolling mill. Lubricant oil was mixed with the cooling water of the finish hot rolling mill in an emulsion state. The amount mixed was adjusted to change the average coefficient of friction. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forward slip ratio in the stands and then taking the average of the same. Further, to prevent the occurrence of slip between the steel sheet and the work roll during the finish hot rolling and the formation of defects on the surface of the steel sheet, the rough rolled sheet bar was welded to she preceding sheet bar and the finish hot rolling continuously performed. The strain rate of the final stand was made 305 s^{-1}. The hot rolling finishing temperature was made 1050°C, the non-coolant time was made 3 seconds, water was then injected for cooling, and the sheet was coiled at 680°C.

Next, the steel sheet was pickled and finished to a thickness of 0.35 mm by cold rolling. This was then annealed by being held in a continuous annealing furnace at 1050°C for 10 seconds in a front stage and held at 900°C for 30 seconds. Next, Epstein specimens were cut out and measured for magnetic properties. Tale 40 shows the results of measurement of the magnetic properties for the present invention and comparative examples together.

As shown in Table 40, if the average coefficient of friction at the time of the finish hot rolling is reduced to less than 0.25, the strain rate is made it least 150 s^{-1} at least at one pass, and a suitable non-water injection time is set, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Table 39

Composition of Material Used					
C	Si	Mn	S	sol-Al	N
0.0017	3.04	0.12	0.0019	0.25	0.0017

Table 22

Results of Measurement of Magnetism			
	Average coefficient of friction at finish rolling	Magnetic flux density B50 (T)	Iron loss W15/50 (W/kg)
Invention	0.19	1.679	2.43
Invention	0.21	1.678	2.45
Comp. Ex.	0.26	1.664	2.63
Comp. Ex.	0.32	1.663	2.66

〈Example 18〉

A slab for non-oriented electrical steel sheet having the composition shown in Table 41 was heated by an ordinary method, was finished to a sheet bar of a thickness of 50 mm by a roughing mill, then was finished to 2.5 mm by a finish hot rolling mill. Lubricant oil was mixed with the cooling water of the finish hot rolling mill. The amount mixed was adjusted to 3% by percent volume to make the average coefficient of friction 0.22. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forward slip ratio in the stands and then taking the average of the same. The strain rate at the final stand was made 270 s^{-1}. The temperature at the end of the hot rolling was made a constant 1050°C, the non-coolant time was changed, and the coiling temperature was made a constant 680°C. In this case, the non-coolant time defined by formula (2) according to the present invention was made 1.2 seconds to 7.2 seconds.

Next, the steel sheet was pickled and finished to a thickness of 0.50 mm by cold rolling. This was then annealed in a continuous annealing furnace at 900°C for 30 seconds. Next, Epstein specimens were cut out and measured for magnetic properties. Table 42 shows the hot rolling conditions and the results of measurement of the magnetic properties together.

As shown in Table 42, it was learned that if the non-coolant time is at least 1.2 seconds, good magnetic properties are obtained.

In this way, by reducing the average coefficient of friction at the time of the finish hot rolling, suitably controlling the strain rate, and suitably controlling the cooling conditions after the end of the hot rolling, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Table 41

Composition of Material Used					
C	Si	Mn	S	sol-Al	N
0.0018	2.10	0.11	0.0019	0.26	0.0018

Table 42

Results of Measurement of Magnetism			
	Non-coolant time (sec)	Magnetic flux density B50 (T)	Iron loss W15/50 (W/kg)
Comp. Ex.	0.5	1.665	3.86
Invention	2.0	1.722	3.40
Invention	4.0	1.725	3.39
Invention	6.0	1.727	3.37

⟨Example 19⟩

A slab for non-oriented electrical steel sheet having the composition shown in Table 43 was heated by an ordinary method, was finished to a sheet bar of a thickness of 35 mm by a roughing mill, then was finished to 2.0 mm by a finish hot rolling mill. Lubricant oil was mixed with the cooling water of the finish hot rolling mill. The amount mixed was changed to adjust the average coefficient of friction. The average coefficient of friction was calculated by calculating the coefficients from the actually measured forwarding rates in the stands and then taking the average of the same. At this time, the temperature at the end of the finish hot rolling was made 900°C and the sheet was immediately quenched and coiled at 600°C. The obtained hot rolled steel sheet was annealed in a continuous annealing furnace at 850°C for 2 minutes.

Next, the steel sheet was pickled and finished to a thickness of 0.50 mm by cold rolling. This was then annealed in a continuous annealing furnace at 900°C for 30 seconds. Next, Epstein specimens were cut out and measured for magnetic properties. Table 41 shows the results of measurement of the magnetic properties for the present invention and comparative examples together.

In this way, if the average coefficient of friction at the time of the finish hot rolling is reduced to less than 0.25 and the annealing conditions of the hot rolled steel sheet are suitably controlled, it is possible to obtain a non-oriented electrical steel sheet with a high value of magnetic flux density, a low iron loss, and superior magnetic properties.

Table 43

Composition of Material Used					
C	Si	Mn	S	sol-Al	N
0.0019	1.10	1.30	0.0017	0.24	0.0017

Table 44

Results of Measurement of Magnetism			
	Average coefficient of friction at finish rolling	Magnetic flux density B50 (T)	Iron loss W15/50 (W/kg)
Invention	0.11	1.755	3.35
Invention	0.16	1.754	3.37
Invention	0.20	1.752	3.39
Comp. Ex.	0.27	1.732	4.15
Comp. Ex.	0.35	1.730	4.21

CAPABILITY OF EXPLOITATION IN INDUSTRY

As explained above, according to the present invention, it is possible to produce a non-oriented electrical steel sheet with a high magnetic flux density, a low iron loss, and superior magnetic properties.

Claims

1. A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss comprising using a slab of steel containing

$1.00\% < Si \leq 7.00\%$
$0.10\% \leq Mn \leq 1.50\%$
$C \leq 0.0050\%$
$N \leq 0.0050\%$
$S \leq 0.0050\%$

and a balance of Fe and unavoidable impurities, hot rolling it to make a hot rolled steel sheet, applying one or two or more cold rolling processes with annealing step, then applying finishing annealing,

said process for the production of a non-oriented electrical steel sheet characterized in that the average coefficient of friction between the hot rolling roll and steel sheet at the finish hot rolling is not more than 0.25.

2. A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss comprising using a slab of steel containing

$1.00\% < Si \le 7.00\%$
$0.10\% \le Mn \le 1.50\%$
$C \le 0.0050\%$
$N \le 0.0050\%$
$S \le 0.0050\%$

and a balance of Fe and unavoidable impurities, hot rolling it to make a hot rolled steel sheet, applying one or two or more cold rolling processes with annealing step, then applying finishing annealing,

said process for the production of a non-oriented electrical steel sheet characterized in that the average coefficient of friction between the hot rolling roll and steel sheet at the finish hot rolling is not more than 0.25 and

the strain rate of at least one pass in the finish hot rolling is at least 150 s^{-1}.

3. A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss as set forth in claims (1) and (2) characterized in that the steel further contains, by wt%, $0.10\% \le Al \le 2.00\%$.

4. A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss as set forth in claims (1), (2) and (3), characterized in that the hot rolled steel sheet is annealed after the end of the finish hot rolling and before the cold rolling by continuous annealing at a temperature of 850°C to 1150°C for 20 seconds to less than 5 minutes.

5. A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss as set forth in claims (1), (2) and (3), characterized in that the hot rolled steel sheet is annealed after the end of the finish hot rolling and before the cold rolling by box annealing at a temperature of 750°C to 850°C for 5 minutes to less than 30 hours.

6. A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss as set forth in claims (1), (2) and (3), characterized in that the hot rolled steel sheet is coiled at a temperature of 750°C to 1000°C and self annealing is performed by the heating held by the coil itself for 5 minutes to 5 hours after the end of the finish hot rolling.

7. A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss as set forth in claims (1), (2) and (3), characterized in that coolant is not performed and the hot rolled steel sheet is coiled during the time t (seconds) defined by the following formulas after the end of the hot rolling at the temperature T (°C) of the end of the finish hot rolling:

$$950 \le T\ (°C) \le 1150 \qquad \text{Formula (1)}$$

$$9.6 - 8 \times 10 - 3T \le t\ (\text{seconds}) \le 15.6 - 8 \times 10 - 3T \qquad \text{Formula (2)}$$

8. A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss as set forth in claims (1), (2), (3), (4), (5), (6) and (7), said process for the production of a non-oriented electrical steel sheet comprising applying a skin pass rolling process with a reduction ratio of 2 to 20% after the finishing annealing.

9. A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss as set forth in claims (1), (2), (3), (4), (5), (6), (7) and (8), characterized in that lubricant oil is added to the cooling water of the hot rolling roll in an emulsion state in a ratio of volume of 0.5 to 20% as a lubricant at the finish hot rolling.

10. A method for producing a non-oriented electrical steel sheet with a high magnetic flux density and a low iron loss as set forth in claims (1), (2), (3), (4), (5), (6), (7), (8) and (9), characterized by joining the sheet bar after the rough rolling with the preceding sheet bar before the finish hot rolling to connect the sheet bars and performing the finish hot rolling on the same.

Fig.1

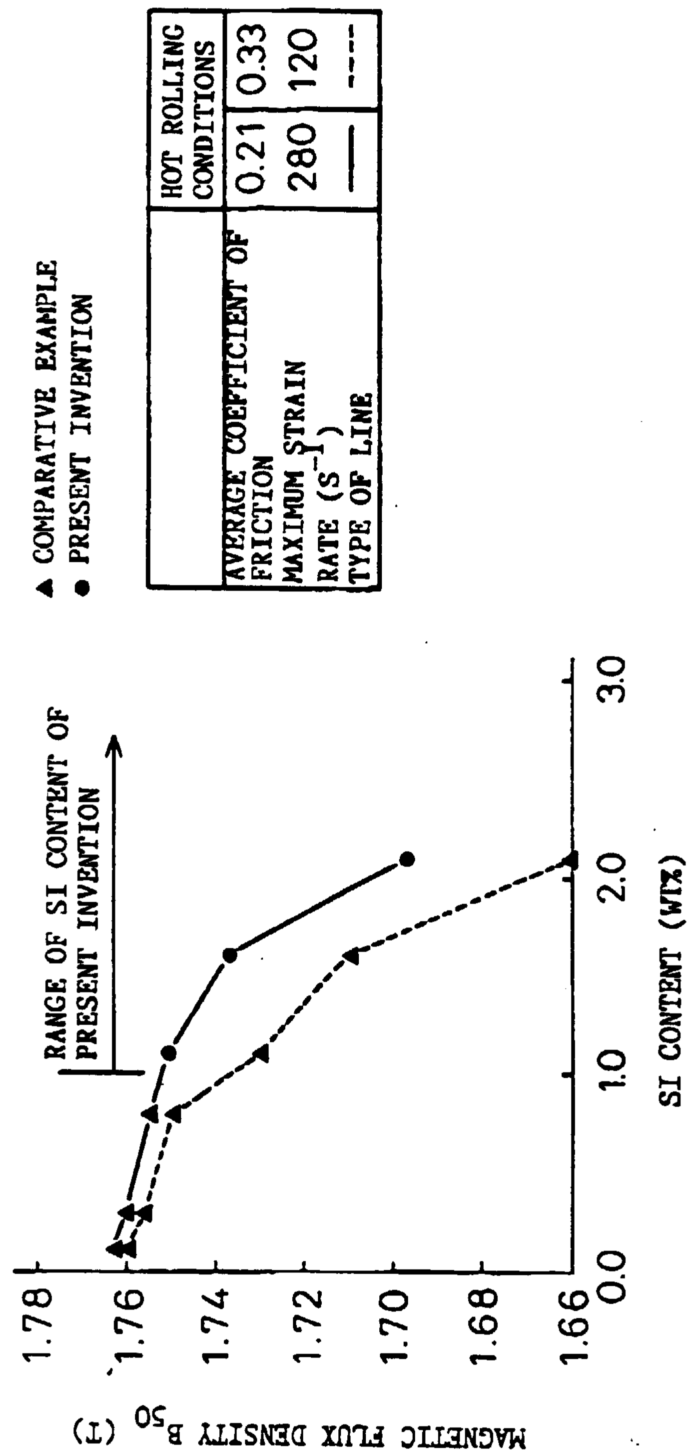

▲ COMPARATIVE EXAMPLE
● PRESENT INVENTION
HOT ROLLING CONDITIONS
AVERAGE COEFFICIENT OF FRICTION
0.21
0.33
MAXIMUM STRAIN RATE (S⁻¹)
280
120
TYPE OF LINE
RANGE OF SI CONTENT OF PRESENT INVENTION
MAGNETIC FLUX DENSITY B50 (T)
1.78
1.76
1.74
1.72
1.70
1.68
1.66
0.0
1.0
2.0
3.0
SI CONTENT (WT%)

Fig.2

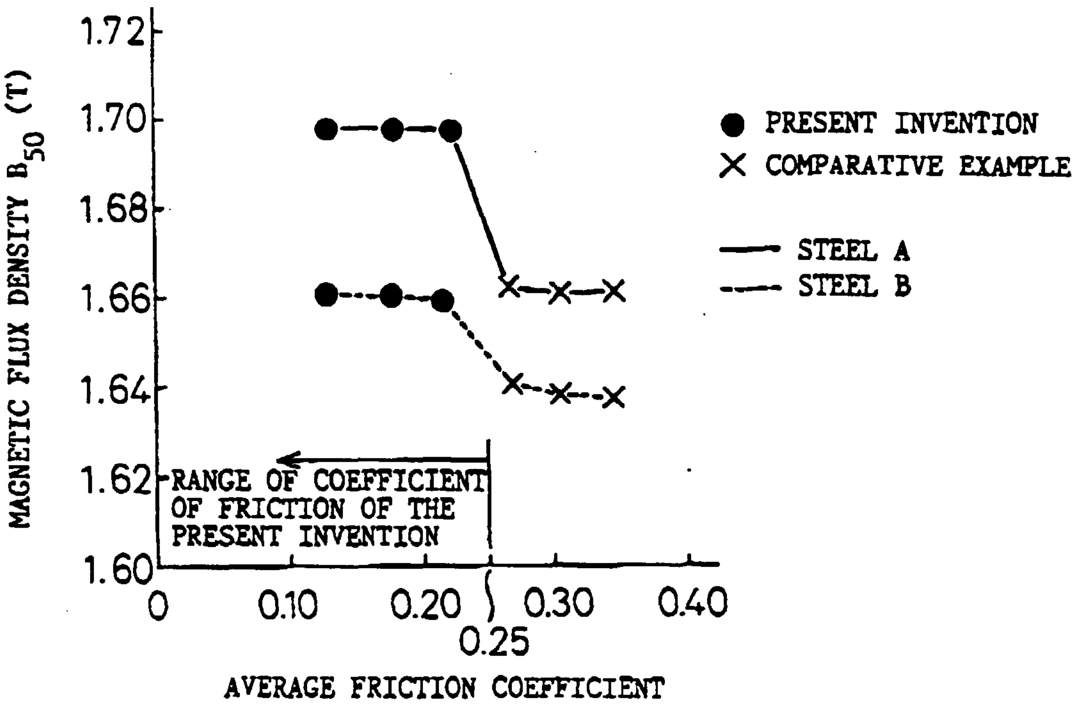

MAGNETIC FLUX DENSITY B_{50} (T)
1.72
1.70
1.68
1.66
1.64
1.62
1.60
RANGE OF COEFFICIENT OF FRICTION OF THE PRESENT INVENTION
0
0.10
0.20
0.25
0.30
0.40
AVERAGE FRICTION COEFFICIENT
● PRESENT INVENTION
× COMPARATIVE EXAMPLE
STEEL A
STEEL B

Fig.3

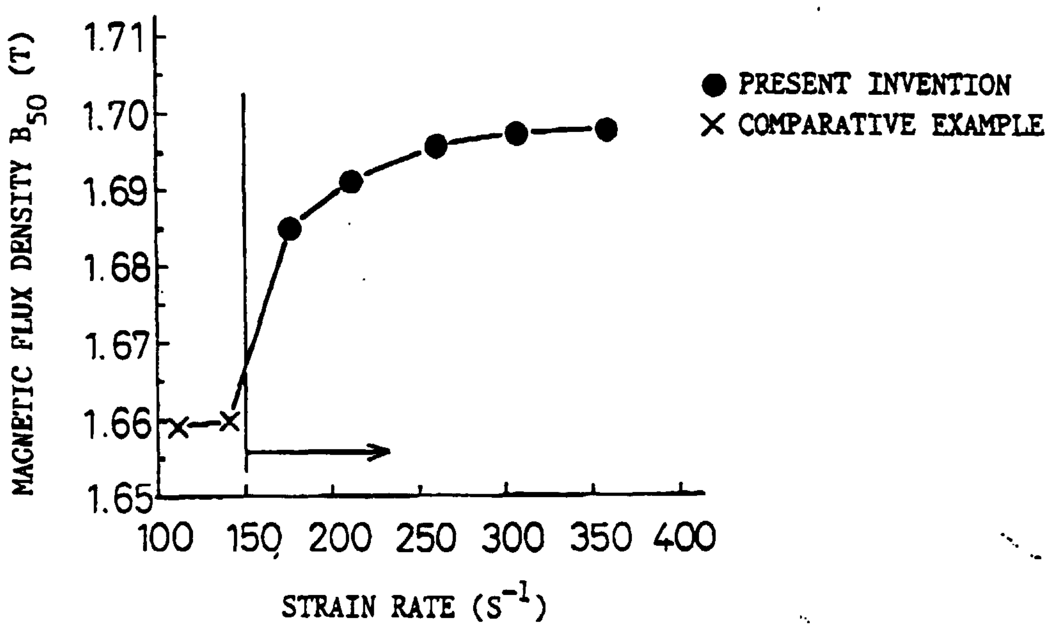

MAGNETIC FLUX DENSITY B_{50} (T)
1.71
1.70
1.69
1.68
1.67
1.66
1.65
100
150
200
250
300
350
400
STRAIN RATE (S^{-1})
● PRESENT INVENTION
× COMPARATIVE EXAMPLE

Fig.4

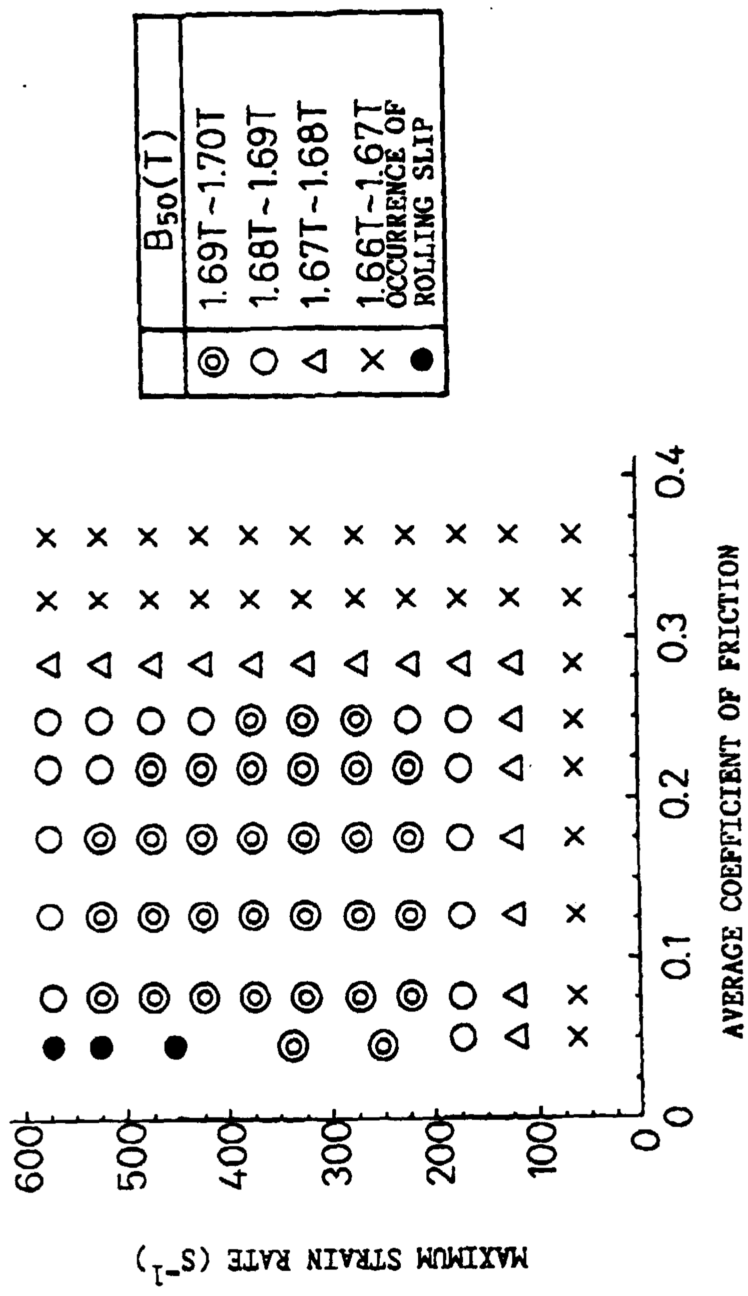
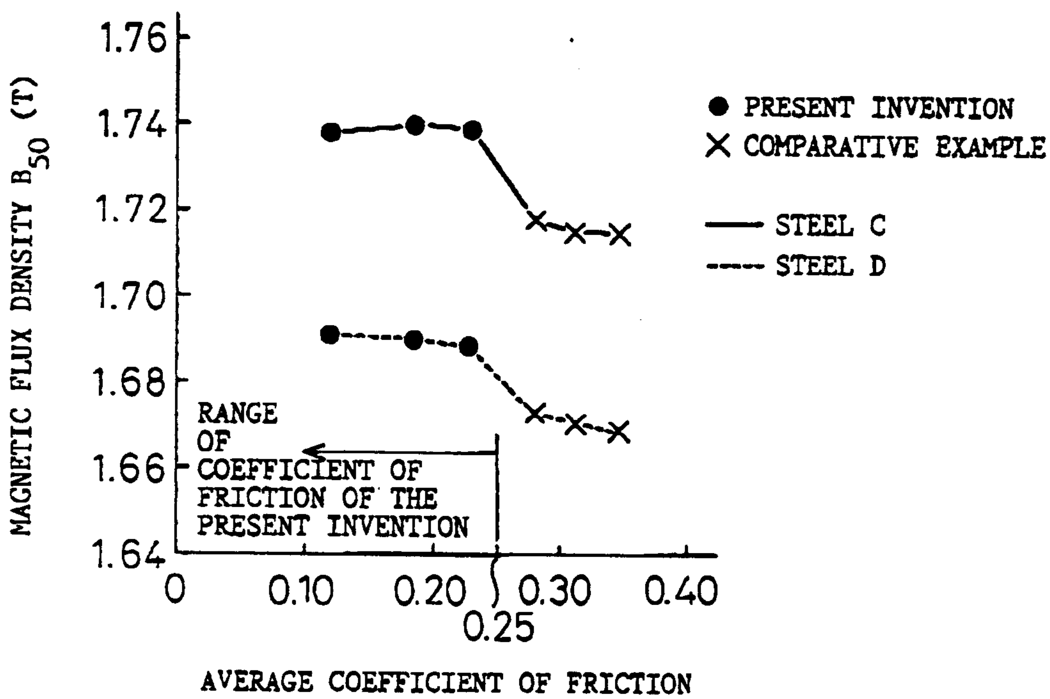
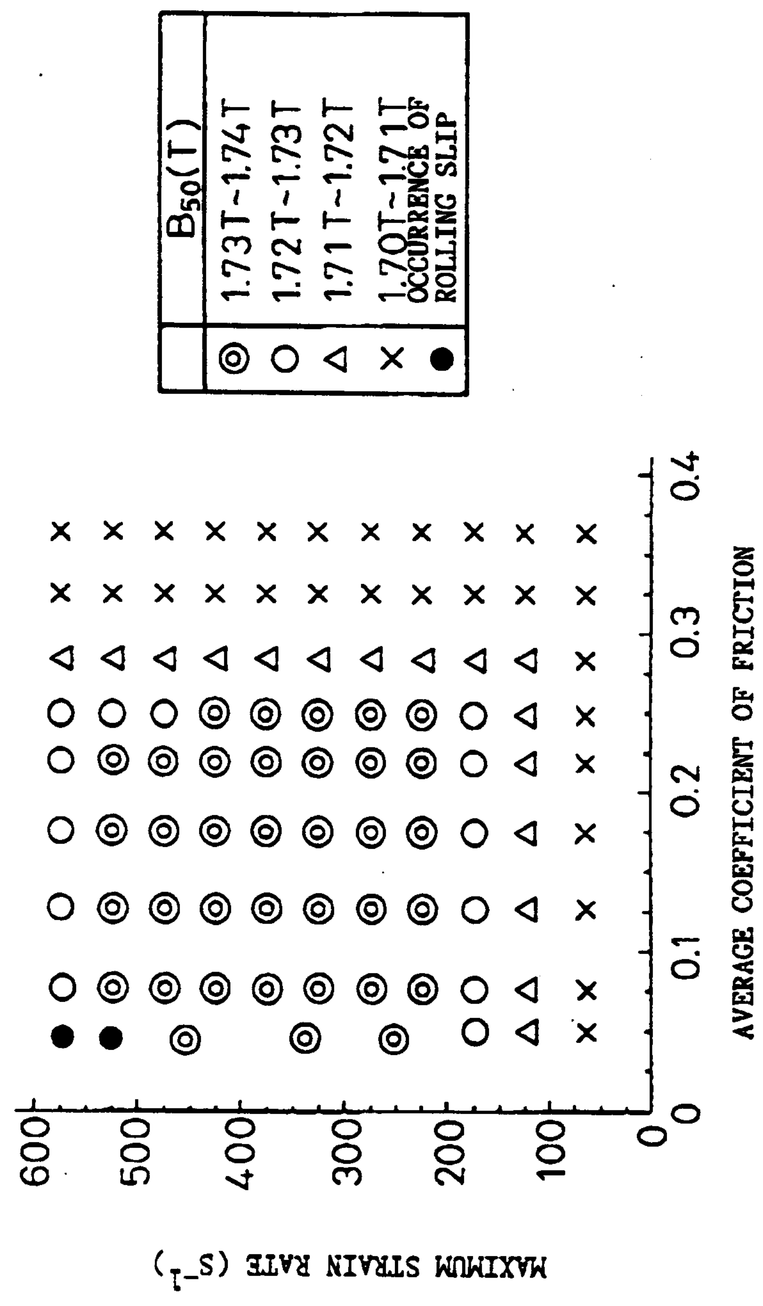

B50(T)
1.69T~1.70T
1.68T~1.69T
1.67T~1.68T
1.66T~1.67T
OCCURRENCE OF ROLLING SLIP
MAXIMUM STRAIN RATE (S-1)
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
AVERAGE COEFFICIENT OF FRICTION

Fig.5



MAGNETIC FLUX DENSITY B_{50} (T)
1.76
1.74
1.72
1.70
1.68
1.66
1.64
0
0.10
0.20
0.25
0.30
0.40
AVERAGE COEFFICIENT OF FRICTION
RANGE OF COEFFICIENT OF FRICTION OF THE PRESENT INVENTION
● PRESENT INVENTION
× COMPARATIVE EXAMPLE
STEEL C
STEEL D

Fig.6



B_{50}(T)
1.73T~1.74T
1.72T~1.73T
1.71T~1.72T
1.70T~1.71T
OCCURRENCE OF ROLLING SLIP
MAXIMUM STRAIN RATE (S^{-1})
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
AVERAGE COEFFICIENT OF FRICTION

Fig.7

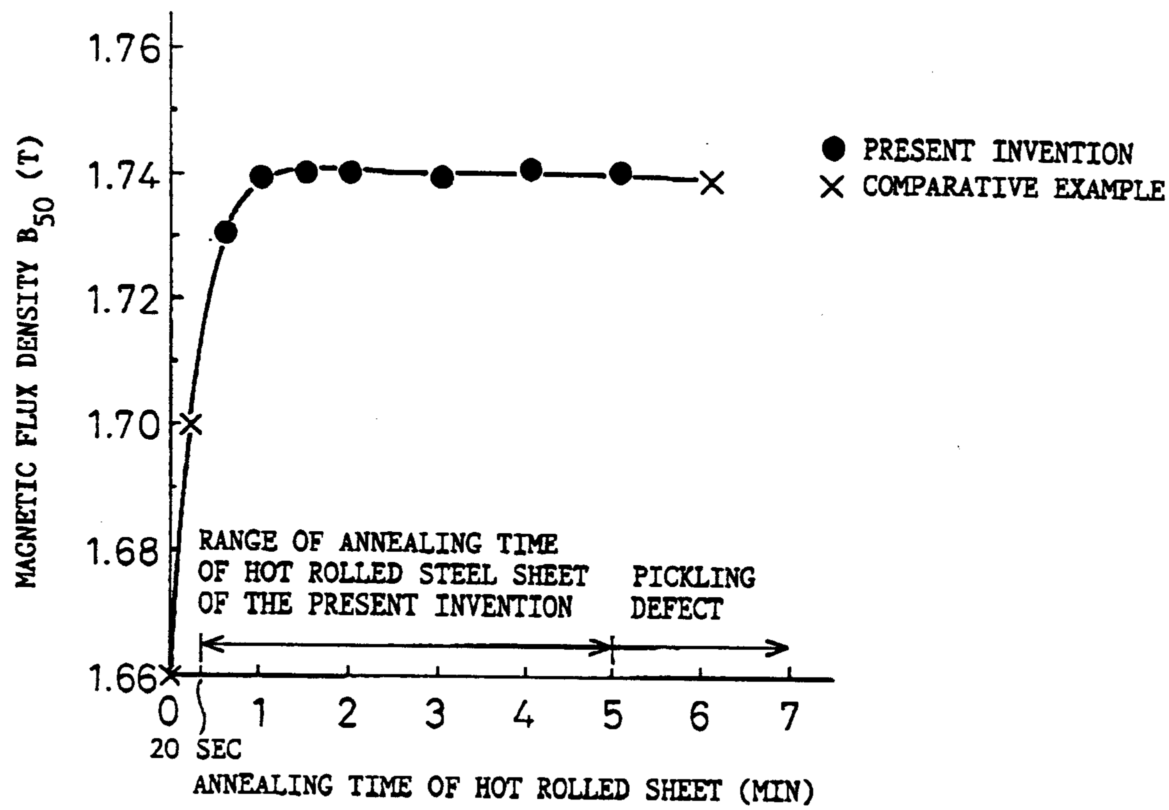

MAGNETIC FLUX DENSITY B_{50} (T)
1.76
1.74
1.72
1.70
1.68
1.66
● PRESENT INVENTION
× COMPARATIVE EXAMPLE
RANGE OF ANNEALING TIME
OF HOT ROLLED STEEL SHEET
OF THE PRESENT INVENTION
PICKLING
DEFECT
0
20 SEC
1
2
3
4
5
6
7
ANNEALING TIME OF HOT ROLLED SHEET (MIN)

Fig.8

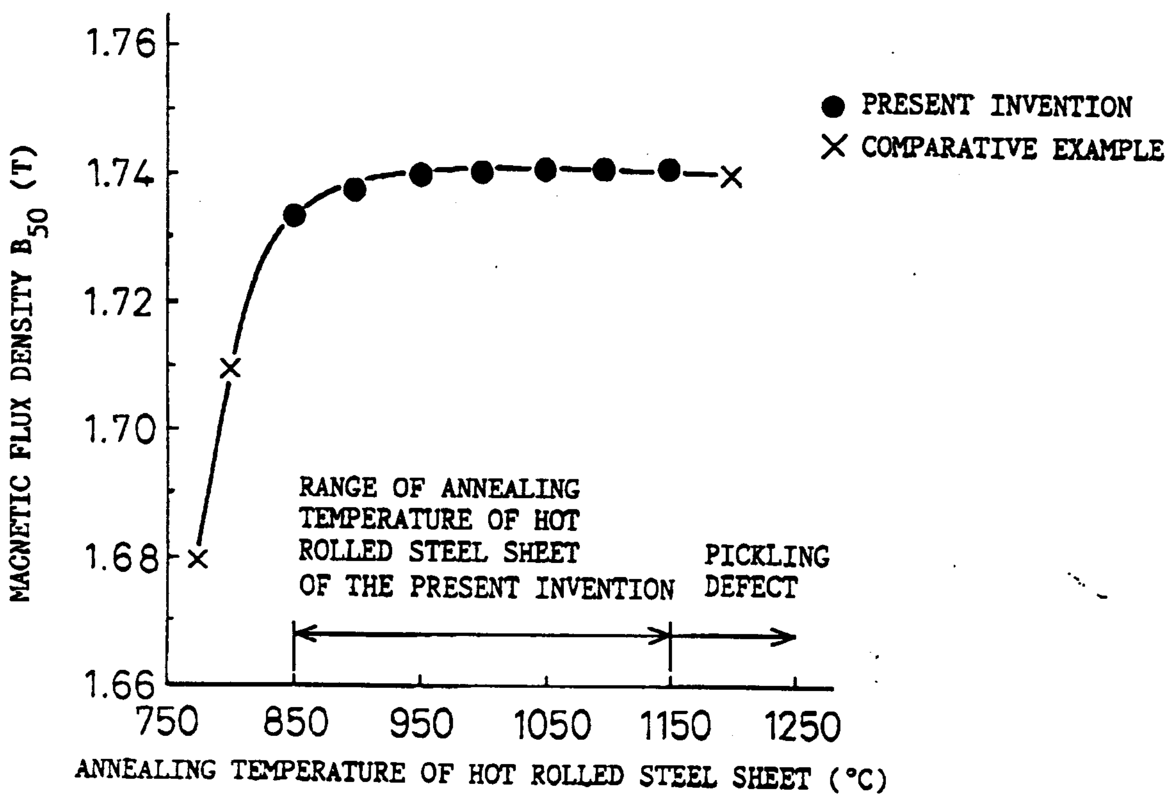

MAGNETIC FLUX DENSITY B_{50} (T)
1.76
1.74
1.72
1.70
1.68
1.66
● PRESENT INVENTION
× COMPARATIVE EXAMPLE
RANGE OF ANNEALING
TEMPERATURE OF HOT
ROLLED STEEL SHEET
OF THE PRESENT INVENTION
PICKLING
DEFECT
750
850
950
1050
1150
1250
ANNEALING TEMPERATURE OF HOT ROLLED STEEL SHEET (°C)

Fig.9

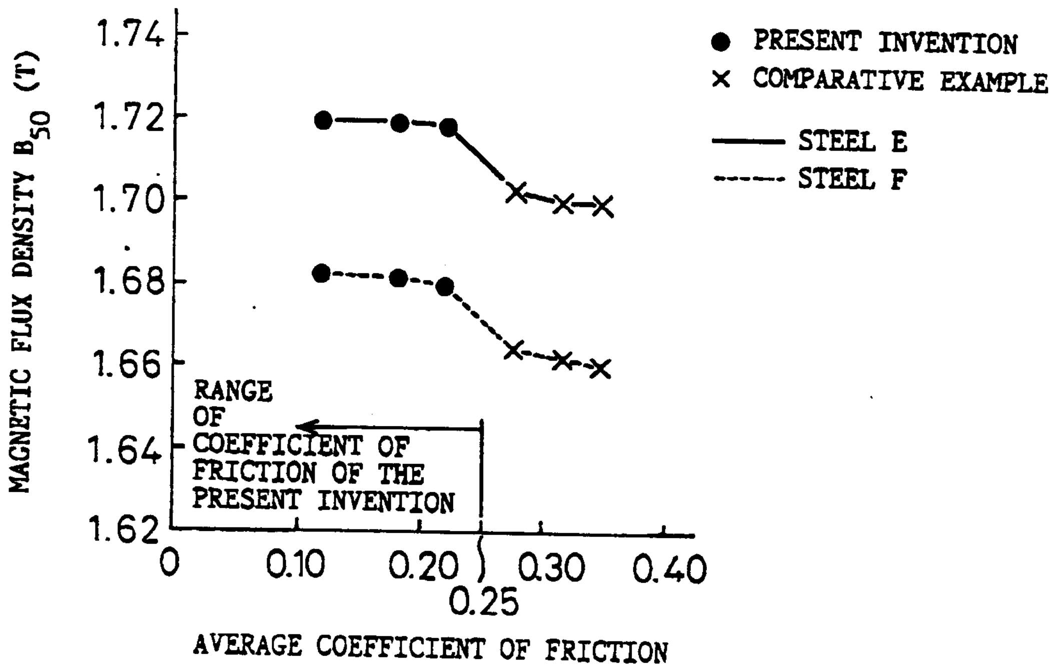

MAGNETIC FLUX DENSITY B_{50} (T)
1.74
1.72
1.70
1.68
1.66
1.64
1.62
0
0.10
0.20
0.25
0.30
0.40
RANGE OF COEFFICIENT OF FRICTION OF THE PRESENT INVENTION
AVERAGE COEFFICIENT OF FRICTION
● PRESENT INVENTION
× COMPARATIVE EXAMPLE
STEEL E
STEEL F

Fig.10

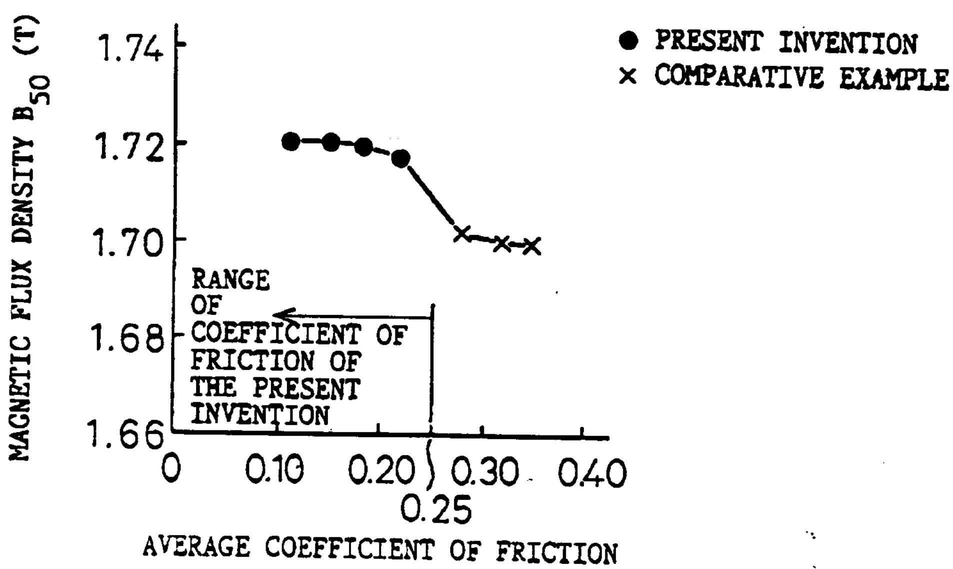
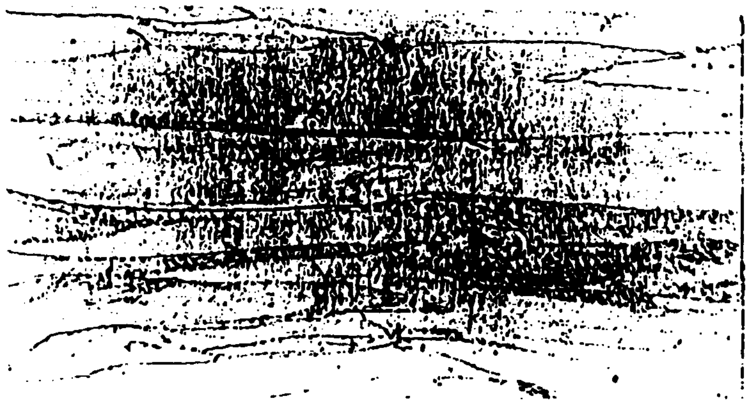

MAGNETIC FLUX DENSITY B_{50} (T)
1.74
1.72
1.70
1.68
1.66
0
0.10
0.20
0.25
0.30
0.40
RANGE OF COEFFICIENT OF FRICTION OF THE PRESENT INVENTION
AVERAGE COEFFICIENT OF FRICTION
● PRESENT INVENTION
× COMPARATIVE EXAMPLE

Fig.11A



SURFACE LAYER PORTION
OF PRESENT INVENTION

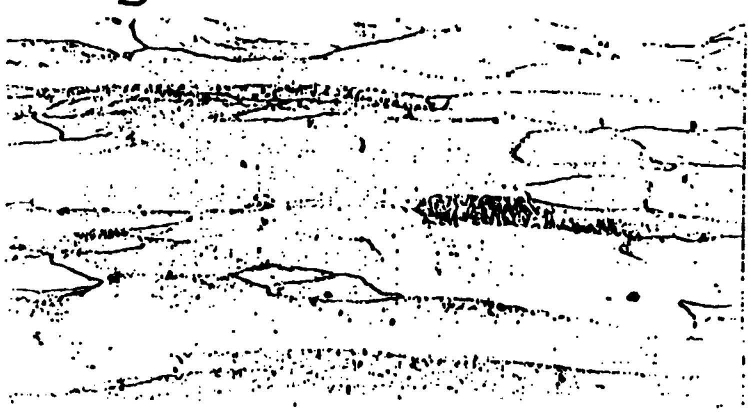
50µm

Fig.11B

SURFACE LAYER PORTION
OF COMPARATIVE EXAMPLE

50µm

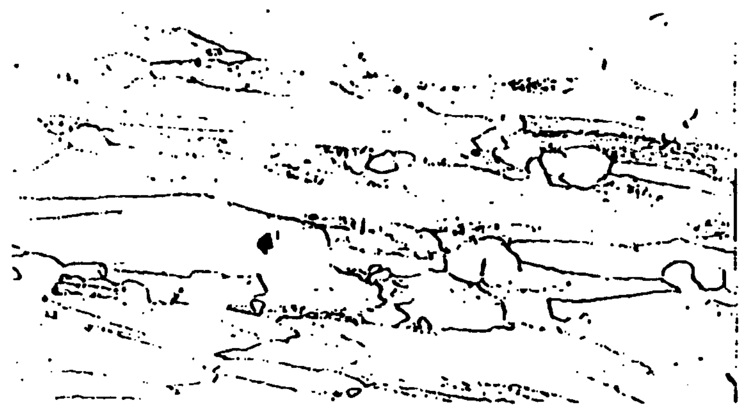
Fig.11C



CENTER LAYER OF PRESENT INVENTION
AVERAGE COEFFICIENT OF FRICTION 0.19

50µm

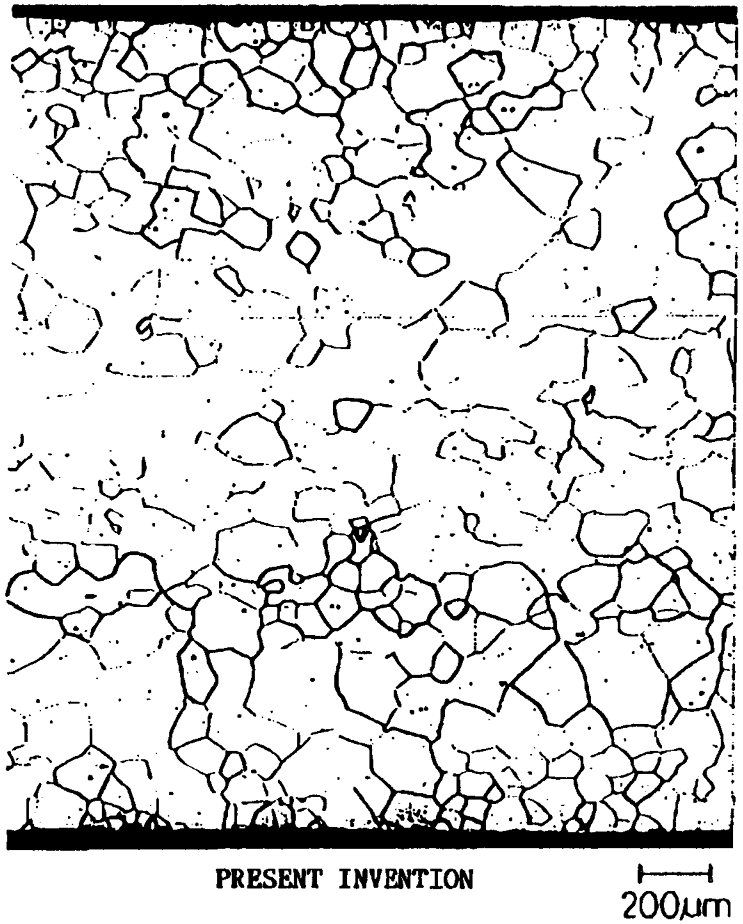
Fig.11D



CENTER LAYER OF COMPARATIVE EXAMPLE
AVERAGE COEFFICIENT OF FRICTION 0.35

50µm

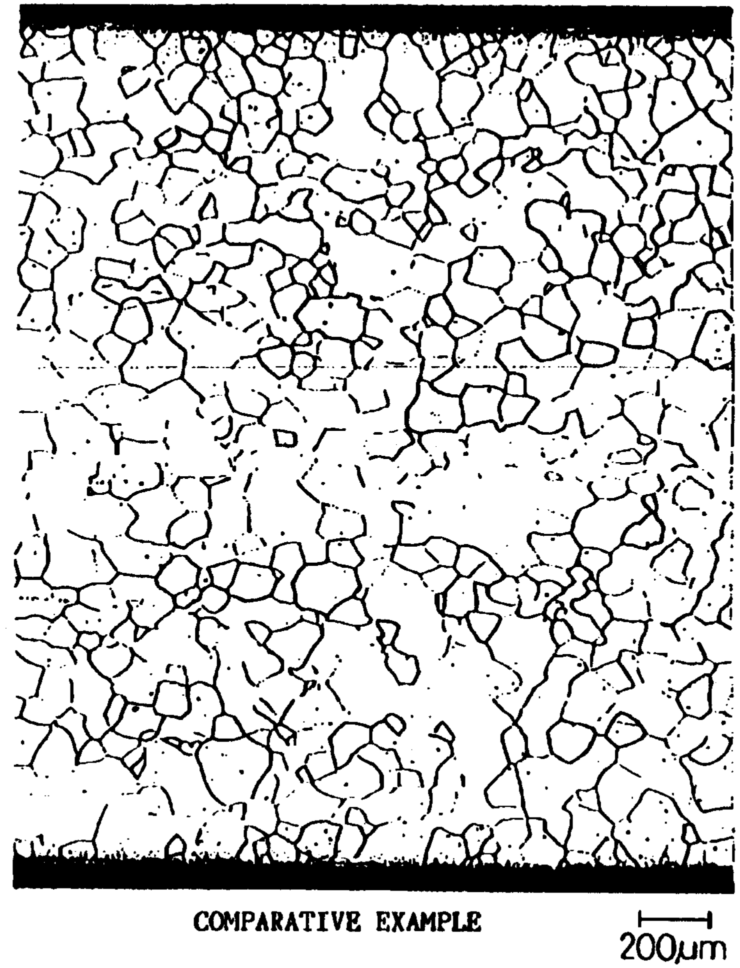
Fig.12A



PRESENT INVENTION

AVERAGE COEFFICIENT OF FRICTION 0.20

Fig.12B



COMPARATIVE EXAMPLE

AVERAGE COEFFICIENT OF FRICTION 0.35

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP96/03570

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl^6 C21D8/12

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)

Int. Cl^6 C21D8/12

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

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.
X Y A	JP, 1-306524, A (Kobe Steel, Ltd.), December 11, 1989 (11. 12. 89)(Family: none) Page 2, upper left column, line 20 to lower right column, line 18; Page 5, example 2	1, 3-5, 8, 9 6, 7, 10 2
Y	JP, 54-76422, A (Nippon Steel Corp.), June 19, 1979 (19. 06. 79)(Family: none) Claim	6
Y	JP, 62-61644, B2 (Nippon Steel Corp.), December 22, 1987 (22. 12. 87)(Family: none) Claim	7
Y	JP, 4-224622, A (Kawasaki Steel Corp.), August 13, 1992 (13. 08. 92)(Family: none) Claim; Figs. 1, 2	10
A	JP, 2-104619, A (Nippon Steel Corp.), April 17, 1990 (17. 04. 90)(Family: none)	1 - 10
A	JP, 6-220537, A (Kawasaki Steel Corp.),	2

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "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	Date of mailing of the international search report
March 3, 1997 (03. 03. 97)	March 18, 1997 (18. 03. 97)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP96/03570

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	August 9, 1994 (09. 08. 94)(Family: none)	

Form PCT/ISA/210 (continuation of second sheet) (July 1992)