NEW PROCESS FOR THE PRODUCTION OF GRAIN ORIENTED ELECTRICAL STEEL FROM THIN SLABS

A careful definition of the steel composition, in particular shifting to low values the content of elements such as carbon, sulfur, aluminum and nitrogen, allows to lower the temperature of some process steps, thus limiting also complexity and cost of relevant plants, and to reduce the influence of the solidification structure on the final quality of the product. If is thus possible to utilize also for grain oriented silicon steels the thin slab continuous casting technique.
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NEW PROCESS FOR THE PRODUCTION OF GRAIN ORIENTED ELECTRICAL STEEL FROM THIN SLABS

FIELD OF THE INVENTION

The present invention refers to a new process for the production of grain oriented electrical steel from thin strips and, more precisely, refers to a process utilizing specific steel composition in combination relationship with specific thin slab continuous casting parameters, to allow a lowering of treating temperatures and a strong decriticization of the whole transformation process, rendering it similar to the treating processes for normal carbon steels.

BACKGROUND OF THE INVENTION

Before describing the state of the art referring to this kind of products, it seems appropriate to remind relevant scientific and technical basis.

Silicon steel consists of a plurality of separate contiguous grains (or crystals), each having a body-centered cubic lattice, in which the axes corresponding to the cube corners, crystallographically designed with [100], are directions of easiest magnetization.

Considering the structure of the most common product utilizing oriented grain electrical steel strip, i.e. nuclei for electric transformers, which are formed by stacks of silicon steel relatively narrow bands cut parallelely to the rolled strip length and wound in form of torus, and the working scheme of transformers, in which a magnetic field induces in the nucleus a magnetic flux directed along the lines of easiest magnetization of the material forming the nucleus itself, it follows that the [001] axes should preferably lay parallel to the rolling direction of the strip, i.e. to the strip length.
Moreover, it is necessary that the lattices of said grains are all oriented in the same way, with the minimum degree of mutual disorientation.

Further, it is necessary that number and dimensions of said grains are maintained within given limits, well known to the experts.

Only by keeping said general conditions it is possible to obtain a material having good magnetization characteristics, i.e. magnetic permeability, expressed as magnetic flux density induced in the nucleus by a magnetic field of given value, and energy loss in operation, usually referred to as core losses at given frequency and permeability and expressed in W/kg.

The best final dimensions and the correct orientation of grains in the end product is obtained during a termal treatment called secondary recrystallization annealing, in which it is possible to allow the growth only of grains having the desired orientation at the beginning of the annealing. Number and dimensions of the grains thus obtained somewhat depend from the corresponding starting values.

When the steel is heated, at a given temperature the grain growth process starts in which the larger ones or those which, for kinetic and/or energetic reasons are more "charged" than the others, start to grow at the expenses of adjacent crystals. During the final secondary recrystallization annealing, the grains having their $<001>$ axis parallel to the strip surface and to the rolling direction of the strip are activated at a lesser temperature than the activating temperature of other crystals, thus more quickly reaching the critical dimensions permitting their predominance in growing.

However, the production process of such steel strips comprises a
number of high-temperature treatments, during some of which a grain
growth could start which, should it occur with wrong modalities and
timing, will prevent to reach the wanted final results.
The secondary recrystallization is controlled by some compounds, such
as manganese sulfide, manganese selenide, aluminum nitride and the
like, which, duly precipitated within the steel, inhibit the grain
growth up to a temperature at which are solubilized, thus permitting
the secondary recrystallization to start.
As the technological aspect is concerned, modern production of grain
oriented silicon steel strips requires preparing a molten steel of
controlled composition, with particular reference to the content of
silicon, carbon, oxygen, manganese, sulfur, aluminum, nitrogen, and
continuously casting it in slabs having a thickness usually comprised
between 15 and 25 cm, a width of around a metre and a length of some
metres.
Such slabs are translated at a temperature of no less than 300 °C, and
then reheated (possibly with a pre-rolling of no more than 25% at
1100-1200 °C) at high temperature, usually at 1300-1400 °C, and hot
rolled; the strip, if necessary annealed, is cold rolled to the final
thickness, usually comprised between 0.18 and 0.35 mm, and then
subjected to a number of high-temperature final treatments, intended
to drastically reduce the carbon content (decarburation annealing),
sulfur and nitrogen, to obtain the desired magnetic properties
(secondary recrystallization annealing), to form on the strip surface
insulating inorganic coatings, for instance magnesium phosphate and
silica based.
Each of the above steps is fundamental for the reaching of final
characteristics of the product, and thus it must be carefully planned and controlled.

For instance, the continuous casting requires a quick initial cooling of the molten steel in the mould, to allow a quick extraction of the slab comprising a solid skin, a soft intermediate mass and a quantity of liquid steel at the centre, which will solidify later. Already from such initial conditions some consequences ensue requiring opportune careful control. In fact, the metal undergo two radically different cooling rates, a first very quick at the surface and then a second more slow at the core, thus solidifying in two different structures, at the surface in small equiaxic crystals and at the core in elongated much larger crystals, called columnar. This starting difference of grain dimensions, if not amended brings after a high-temperature heating to a non homogeneous structure in the final product, and to a lesser quality.

Moreover, the relatively slow cooling rate of the slabs brings both to an abnormal growth of the fraction of columnar crystals with respect to the fraction of the equiaxic ones, and to the segregation of some elements as well as to the coagulation of some compounds, such as manganese sulfide, in large lumps not easily dissolved at the reheating temperatures, which then cannot be reprecipitated as finely dispersed particles, necessary to correctly perform as grain growth inhibitors. Another effect is the abnormal growth of the columnar grains with respect to the equiaxic ones.

Thus, since the very beginning of the production process, it is necessary to accurately control, for instance pre-rolling the slab before its high temperature heating, a number of variables in order to
avoid an excessive dimension difference of grains, and to obtain a sufficiently fine and homogeneous distribution of inhibitors. To obtain the above, the slabs are heated at high temperature, typically above 1330 °C, to dissolve the compounds precipitated during the slab cooling as large lumps, and to allow them to be more homogeneously diffused, and reprecipitated during the cooling, within the metal. The furnaces usually utilized to reach such a high heating temperature have a number of inconveniences, among which very important are temperature differences found between surface and core of the slabs and the high overheating of the slab surface, necessary to let the core assume the desired temperature within an acceptable period of time, which factors induce an unwanted grain growth, as well as the formation of liquid slag on the slab surface, which calls for special extremely costly furnaces.

During the hot rolling process, the metal undergoes a thickness reduction at such temperature and reduction rates to obtain acceptable grain dimensions and to precipitate in fine particles, due to the cooling, the above mentioned compounds, such as manganese sulfide. To obtain the desired grain dimensions, a pre-rolling is usually utilized, consisting in a first hot rolling pass carried out before the maximum heating temperature is reached; this obviously calls for higher costs, mainly due to the fact that slabs have to be extracted from the furnace, rolled and then put again in the furnace.

It is easy to understand now how complex and costly is the production of a good grain oriented silicon steel strip, and hence how important is to utilize in the more efficient way any possible technique to reduce production costs.
Thus it is highly desirable to simplify the production process of this kind of steel through the elimination, or at least the reduction, of some critical steps.

As already mentioned, the steel solification conditions have a great importance in defining the crystalline structure of the steel; it is necessary to recall that in the continuous casting of thick slabs, the slab skin undergoes high cooling rates, with formation of very small crystals, while the core is slowly cooled, forming large, elongated crystals. This causes different behaviours of such different crystalline zones during the heating at high temperature and, therefore, can cause a deterioration of the magnetic properties of the final product, should this situation be not controlled, or a rise of production costs.

For different reasons and for different steels, in particular for carbon steels, new methods of low-thickness continuous casting have been devised, in particular the strip casting, in which the cast product has a thickness of less than 15 mm, and the thin slab casting, in which the cast product has a thickness of some tens of millimetres, typically 40-100 mm.

The experience gained with common steels, points out that the thin slab continuous casting cannot solve the problem of different grain dimensions at the surface and in the core; hence, the common behaviour is that such technology is not advantageous in the production of electrical silicon steels, in that it keeps the complexities of the classic production processes of said steels and adds the need of a new kind of casting machine, whose management moreover is not simple.

The interest of the majority of the steel producers is hence directed
to the strip continuous casting, in which practically no problems due
to different solidification structures are encountered. However, also
this technology did not have a full industrial utilization; one of the
reasons for this could be the unsatisfactory surface quality of the
strip, the initial roughness being not eliminable with the low
reduction rates necessary to pass from some mm to some tens of mm.
Other tentatives to simplify the process consist in eliminating the
prerolling step and in reducing the slab heating temperature before
hot rolling; this last step being particularly costly, essentially due
to the high temperature to be reached, the long treating time, the
large dimensions of the slabs to be treated and the necessity to
utilize specific furnaces, as already mentioned.
Concerning this last aspect, since the dissolution temperature of
manganese sulfide in the steel is a function of a number of factors,
among which the content of oxygen (and then of the internal oxidation
level of the steel), manganese and sulfur, by careful controlling such
elements it is possible to reduce by many tens of degrees the slab
heating temperature.
Another crytical aspect is the final annealings, in order to eliminate
some elements such as carbon (continuous annealing) and sulfur (box
annealing), said elements having an adverse influence on the quality.
Such annealings have to be carefully controlled in that they favour
gas-solid reactions and because some dangerous phenomena have to be
avoided, such as random orientation grain growth.
It is also necessary to point out that different kinds of electrical
steels exist, mainly divided into the kinds (1) conventionally
oriented grain having, for a sheet thickness of 0.30 mm, permeability
higher than 1.78 Tesla (T) and core losses (P17) lower than 1.55 W/kg at 50 Hz, and (ii) super-oriented grain, with permeability higher than 1.88 T and core losses lower than 1.11 W/kg, each kind of product having its own specific process characteristics.

Thus, for instance, in the composition of conventional grain oriented sheets there is no aluminum, which is deemed to adversely affect the final magnetic properties in that it forms undesired oxide precipitates, while in the super-oriented kind aluminum is specifically utilized, in small percentage, essentially to combine with specific amounts of nitrogen to form aluminum nitride, utilized as grain growth inhibitor at temperatures higher than solubilization temperature of manganese sulfide; thus two seemingly similar compositions, being in effect very low the contents of aluminum, nitrogen and oxygen, bring to products having sharply different characteristics.

The efforts up to now put into practice did permit to obtain good results, not so good however to eliminate some important process complexities.

Summing up, in spite of important industrial and research efforts, the production of electrical silicon steel strip still remains a complex and costly process, comprising many critical points to be carefully controlled to avoid quality losses and ensuing heavy downgrading.

STATE OF THE ART

Up to now, we have no information referring to the thin-slab continuous casting of grain oriented silicon steels; as far as thin-slab casting is concerned, the existing literature is dedicated to conventional carbon steels while, for silicon steels, some information
were found referring to continuous casting of strips (thickness of less than 10 mm).

However, some data referring to thick-slab continuous casting are hereinbelow reported.

Published German patent application DE 4,311,151 refers to a steel comprising, in wt %, C 0.02-0.10, Si 2.5-5, Mn 0.04-0.15, S 0.010, Al 0.010-0.035, N 0.0045-0.0120, Cu 0.020-0.300, remaining being essentially iron; slabs of this steel are heated at a temperature insufficient to dissolve manganese sulfide but sufficient to dissolve copper sulfide; the slabs are then hot rolled with an end-rolling temperature between 880 and 1000 °C to a thickness of between 1.5 and 7 mm, the strip so obtained is annealed at 880-1150 °C for 100-600 s and then cooled at a rate of 15 °K/s. The secondary recrystallization mechanism is thus controlled by finely precipitated copper sulfide.

In JP 04 301 035-A and 05 295 442-A the cooling rate after the last hot-rolling stand is controlled.

In JP 04 289121-A, the strip is reduced by 0.5-15 % before cold rolling in a rolling stand whose rolls have a diameter of 50 times the strip thickness, and then annealed at 700-1100 °C.

In EP-393508 a process is described referring to a silicon steel comprising, in wt %, C 0.021-0.100, Si 2.5-4.5, one or more elements inhibiting the grain growth such as Al, N, Mn, S, Se, Sb, B, Cu, Bi, Nb, Cr, Sn, Ti. The hot rolled strip is coiled at a temperature comprised between 500 and 700 °C and the coil, of a weight comprised between 5 and 20 t, is cooled in air or preferably in water. The usual cold rolling and annealing follow.

In JP 02 133525-A, the hot rolling ends at a temperature of at least
900 °C and the strip is cooled at a rate of at least 40 °C/s and coiled at a temperature of between 300 and 500 °C.

JP 61 186456 discloses a steel comprising, in wt %, C 0.01-0.06, Si 3.1-4.5, Mn 0.01-0.2, Mo 0.003-0.1, Sb 0.005-0.2, S and/or Se 0.005-0.1, and at least one between Cr 0.01-0.03, Cu 0.01-0.5, Sn 0.005-0.2.

Jp 61 186456 discloses a steel comprising, in wt %, C 0.01-0.06, Si 3.1-4.5, Mn 0.01-0.2, Mo 0.003-0.1, Sb 0.005-0.2, S and/or Se 0.005-0.1, and at least one between Cr 0.01-0.03, Cu 0.01-0.5, Sn 0.005-0.2.

Jp 61 79722-A discloses a steel comprising, in wt %, C < 0.085, Si 2-4, Mn 0.03-0.1, Al 0.01-0.05, Sn 0.03-0.5 and Cu 0.02-0.3; It is specified that Sn contributes in grain refining during the secondary recrystallization and Cu enhances the adherence of final glass films; both said elements are also grain growth inhibitors.

In BE 894039 a steel is disclosed comprising Sn and Cu in a ratio of between 0.5:1 and 1:1. The hot rolled strip is precipitation annealed at 900-1250 °C for 0.5-30 min and then quickly cooled to precipitate AlN.

BE 894038 discloses a treating process for a silicon steel comprising, in wt %, Cu 0.02-0.2, in which the entering temperature of the strip in the last hot-rolling stand is comprised between 1100-1250 °C, while the exit temperature is of 900-1050 °C for the upper part of the strip and of 950-1100 °C for the middle and lower parts.

JP 01 309924-A discloses a treating process for a silicon steel in which a slab is heated at a maximum temperature of 1270 °C, hot rolled at an exit temperature of 700-900 °C and coiled at less than 600 °C.

JP 02 101120-A disclosed a process allowing to eliminate the precipitation annealing, yet permitting to obtain excellent magnetic
characteristics. The process comprises finishing the hot rolling at a temperature higher than 900 °C, with the temperature at the beginning and at the end of the strip within 10 % of its entire length, higher by 50-200 °C than the one of the remaining of the strip, which is coiled at a temperature of more than 700 °C, held at this temperature for 5-60 min and then water cooled.

DESCRIPTION OF THE INVENTION

It is now clear that there is a necessity to simplify the oriented grain silicon steel production processes and to lower their cost. Present invention aims to a simplification of the grain oriented silicon steel production process, by identifying the composition and process conditions allowing to utilize of the thin-slab continuous casting and to optimize the favourable characteristics thereof, in particular to lower the segregation level and to utilize a lower inhibition.

According to the present invention, by carefully choosing the steel composition, in particular by limiting the content of some elements within specific limits, it is possible to drastically reduce the temperature of some important process steps and also to lower the influence on the final quality of the solidification structure obtained during the continuous casting.

As far as the composition is concerned, the carbon content must be kept between 50 and 350 ppm, preferably between 80 and 200 ppm, the sulfur content must be kept between 60 and 220 ppm, preferably between 90 and 170 ppm, the acid soluble aluminum content must be kept between 20 and 100 ppm, preferably at less than 80 ppm, and the nitrogen one must be kept at less than 60 ppm, preferably between 40 and 60 ppm.
The chemical composition of the steel, in wt % unless differently stated, is than choosed according to the following: C 50-350 ppm, Si 2.5-4.0, Mn 0.03-0.10. S 50-220 ppm, Cu 0.1-0.4, P < 0.1, Sn 0.05-0.20, Al 30-100 ppm, N ≤ 60 ppm, remaining being iron and minor impurities. To form grain growth inhibitors the elements Nb, Ti and V can be utilized, with the other elements currently utilized to this purpose, or in substitution thereof.

The above composition is particularly suited for thin-slab continuous casting, with a thickness of less than 100 mm, preferably comprised between 40 and 70 mm. The extraction rate of the slab from the mould must be comprised between 3.0 and 6.0 m/min, and the steel must have a temperature of no more than 40 °C higher than its liquidus temperature, preferably from 20 and 30 °C higher. Hereinafter, this temperature and the prescribed temperature difference will be referred to as, respectively, steel solidification temperature and overheating. The slab cooling is controlled to obtain complete solidification of the steel in less than 120 s, preferably between 40 and 100 s.

The steel coming out from the mould can be hot rolled in-line with the casting, or can be cut in slabs which will be held at a temperature of between 1100 and 1250 °C for 1-15 min; the temperature will have to be kept uniform along the slabs, with temperature variations within 25 °C. At the entrance of the hot rolling finishing stand, the steel temperature will be between 950 and 1100 °C, within 30 °C; a strip is thus produced having a thickness of less than 3 mm, preferably between 2 and 2.5 mm, having a temperature, at the exit from the finishing stand, comprised between 900 and 1050 °C. After 5-10 s from the exit from the finishing stand a forced cooling of the hot rolled strip
starts, preferably in water, and the strip is then coiled at a
temperature comprised between 500 and 800 °C.
Later, the coils are unwound and the strip is annealed at a
temperature of between 900 and 1150 °C, cooled at 850-1000 °C, held at
this temperature and then quickly cooled, preferably in steam-water,
starting from 750-850 °C.
In at least one of the furnace zones in which the strip is held at
constant temperature, the furnace atmosphere is an oxidizing one, so
that the strip is decarburized up to a depth comprised between 10 and
35 % of the strip thickness, preferably between 20 and 30 % of this
thickness.
The strip is then cold rolled, with the last rolling pass producing a
thickness reduction comprised between 60 and 80 %.
During the decarburization and recrystallization annealings, the strip
is treated according the usual procedures. However, the starting steel
composition allows to held, during the decarburization annealing, a
temperature of 800-900 °C, preferably 830-880 °C; the heating rate up
to 750 °C is comprised between 1 and 80 s, preferably between 4 and 60
s.
The present invention will be now illustrated in greater detail with
reference to some exemplificative embodiments, not to be considered
as limiting the scope of the invention itself.
EXAMPLE 1
The following compositions were utilized:
<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>COMPOSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Si, %</td>
<td>3.50</td>
</tr>
<tr>
<td>C, ppm</td>
<td>200</td>
</tr>
<tr>
<td>Mn, ppm</td>
<td>630</td>
</tr>
<tr>
<td>S, ppm</td>
<td>240</td>
</tr>
<tr>
<td>Cu, %</td>
<td>0.09</td>
</tr>
<tr>
<td>Sn, %</td>
<td>0.08</td>
</tr>
<tr>
<td>Al_2, ppm</td>
<td>70</td>
</tr>
<tr>
<td>N, ppm</td>
<td>60</td>
</tr>
</tbody>
</table>

Compositions B, C and G are within the invention, composition A was outside it for the S content, composition D is typical of silicon steel with high permeability (a product with higher quality than the one of present invention), compositions E and F refer to conventional grain oriented strips. Compositions F and G were treated, from the casting on, according to the traditional process for conventional oriented grain steel, well known to the experts.

Compositions A, B, C, D, E were treated according to the following cycle:

**CASTING**

Slabs 60 mm thick were cast, with an overheating of 25 °C and a casting speed of 4.8 m/min; the solidification time was maintained between 55 and 60 s.

The thin slabs were then brought at 1170-1180 °C and hot rolled, with an entering temperature in the finishing stand of 1040 °C, which temperature was kept within 20 °C. The exit temperature from the finishing stand was between 990 and 1010 °C. The final thickness was
2.5 mm. Compositions B, C, D and E were cooled starting 9 s after exit from the finishing stand; composition A was cooled immediately after the finishing stand.

Coiling temperature was 550-600 °C.

The hot rolled strips were continuously annealed by heating at 1000 °C in wet atmosphere, cooling at 850 °C and quenching in boiling water. The strips were then cold rolled down two intermediate thicknesses, of 1.2 mm (for a final thickness of 0.30 mm) and of 0.85 mm (for a final thickness of 0.23 mm); such intermediate strips were annealed at 980 °C for 60 s.

A decarburization annealing followed, at 860 °C with a heating rate up to 750 °C of 15 °C/s.

The final treatments of glass-film formation, thermal flattening and deposition of tensioning coating, were conventional ones.

The magnetic characteristics thus obtained, as magnetic permeability in a field of 800 Ampere/metre, in Tesla (T), and as core losses at 1.5 and 1.7 T and 50 Hz, in W/kg, are reported in the following Table:

<table>
<thead>
<tr>
<th>THICKNESS 0.30 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAGNETIC CHARACTERISTICS</td>
</tr>
<tr>
<td>B(800), T</td>
</tr>
<tr>
<td>P 1.7, W/kg</td>
</tr>
<tr>
<td>P 1.5, W/kg</td>
</tr>
</tbody>
</table>
THICKNESS 0.23 mm

<table>
<thead>
<tr>
<th>CHARACTERISTICS</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_{800}$, T</td>
<td>1.780</td>
<td>1.840</td>
<td>1.850</td>
<td>1.568</td>
<td>1.574</td>
<td>1.840</td>
<td>1.590</td>
</tr>
<tr>
<td>$P_{1.7}$, W/kg</td>
<td>1.48</td>
<td>1.08</td>
<td>1.09</td>
<td>2.40</td>
<td>2.12</td>
<td>1.18</td>
<td>2.05</td>
</tr>
<tr>
<td>$P_{1.5}$, W/kg</td>
<td>0.90</td>
<td>0.65</td>
<td>0.65</td>
<td>1.35</td>
<td>1.39</td>
<td>0.72</td>
<td>1.36</td>
</tr>
</tbody>
</table>

It can be seen how, utilizing the process according to the invention, a product can be obtained having the quality of a good grain oriented product, but with interesting advantages concerning energy savings and cycle simplification.

**EXAMPLE 2**

A steel was prepared having the following composition, in wt % unless otherwise stated.: Si 3.34, C 290 ppm, Mn 700 ppm, S 180 ppm, Cu 0.08, Sn 0.010, Al$_5$ 70 ppm, N 60 ppm.

This composition was treated according to Example 1; the slabs, however, were heated at 1150 °C and the hot rolled strip thickness was 2.1 mm.

The strips were then rolled at the intermediate thicknesses reported in the following Table, and for each intermediate thickness a final reduction ratio was utilized to obtain a final thickness of 0.20 mm. The intermediate strips were annealed at 1000 °C.

In the Table, the magnetic permeabilities, in T, are also reported.

<table>
<thead>
<tr>
<th>INTERMEDIATE THICKNESS (mm)</th>
<th>1.8</th>
<th>1.7</th>
<th>1.5</th>
<th>1.3</th>
<th>1.1</th>
<th>0.9</th>
<th>0.7</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd REDUC. (%)</td>
<td>84</td>
<td>83</td>
<td>81</td>
<td>78</td>
<td>74</td>
<td>68</td>
<td>58</td>
<td>42</td>
</tr>
<tr>
<td>$B_{800}$, T</td>
<td>1.77</td>
<td>1.79</td>
<td>1.84</td>
<td>1.86</td>
<td>1.87</td>
<td>1.86</td>
<td>1.83</td>
<td>1.75</td>
</tr>
</tbody>
</table>
It can be easily seen that only by maintaining the final cold-rolling reduction rate within the limits according to present invention, good final properties can be obtained, in accordance with the kind of product.

**Example 3**

A steel was prepared having the following composition, in wt % unless otherwise defined: Si 3.4, C 150 ppm, Mn 730 ppm, S 150 ppm, Cu 0.20%, %, Sn 0.008, Al 80 ppm, N 50 ppm.

This steel was continuously cast in thin slabs according to Example 1, but part of the steel was cast with a 50 °C overheating (composition A), the remaining with a 25 °C overheating.

In the following table the obtained magnetic characteristics are reported for final strip thicknesses of 0.30 and 0.23 mm:

<table>
<thead>
<tr>
<th>MAGNETIC CHARACTER</th>
<th>CONDITION A</th>
<th>CONDITION B</th>
</tr>
</thead>
<tbody>
<tr>
<td>B(800), T</td>
<td>1805</td>
<td>1850</td>
</tr>
<tr>
<td>P 1.7, W/kg</td>
<td>1.21</td>
<td>1.12</td>
</tr>
<tr>
<td>P 1.5, W/kg</td>
<td>0.83</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Also in this case the necessity to follow the present invention can be appreciated, as well as the criticality of the casting conditions, which allow to obtain good magnetic characteristics values, in line with those of the best products on the market.

Other examples, exploring the above identified composition and process fields according to the invention, gave similar results to those above reported.
CLAIMS

1. A process for the production of grain oriented silicon steel strips, in which a steel of given composition is melted, continuously cast in thin slabs which are then hot rolled to obtain a strip of desired thickness, said strip being coiled and subsequently uncoiled and cold rolled to the final desired thickness, said cold rolled strip undergoing final treatments comprising decarburizing and recrystallization annealings, characterized in that it comprises the combination in cooperation relationship of the following steps:

a) choosing a composition of steel comprising, in wt % unless differently stated, C 50-350 ppm; Si 2.5-4.0; Mn 0.03-0.10; S 50-220 ppm; Cu 0.1-0.4; P < 0.1; Sn 0.05-0.20; AlS 30-100 ppm; N ≤ 60 ppm, remaining being iron and minor impurities;

b) continuously casting said steel in thin-slabs having a thickness of less than 100 mm, the steel having a temperature of no more than 40 °C higher than its liquidus temperature, utilizing an extraction rate of the slab from the mould comprised between 3.0 and 6.0 m/min, the slab cooling being controlled to obtain complete solidification of the steel in less than 120 s;

c) hot rolling the slabs, maintaining its temperature, at the entrance of the hot rolling finishing stand, between 950 and 1100 °C ± 30 °C, while at the exit from the finishing stand the temperature is maintained between 900 and 1050 ºC;

d) starting a forced cooling of the hot rolled strip from 5-10 s after the exit from the finishing stand, the strip being then coiled at a temperature comprised between 500 and 800 ºC;

e) annealing the strip at a temperature of between 900 and 1150 ºC in
a controlled oxidizing atmosphere, cooling it at 850-1000 °C and then
quickly cooling from 750-850 °C;
f) cold rolling the strip at the final thickness in at least two
rolling steps;
g) heating the strip during the decarburization annealing at a rate,
up to 750 °C, comprised between 1 and 80 s.

2. Process according to claim 1, characterized in that the carbon
content of the steel is comprised between 0.008 and 0.020 %, in
weight.

3. Process according to any one of the above claims, in which the
sulfur content of the steel is comprised between 0.0090 and 0.0170 %,
in weight.

4. Process according to any one of the above claims, in which the
nitrogen content of the steel is comprised between 0.0040 and 0.0060
%, in weight.

5. Process according to any one of the above claims, in which the
acid soluble aluminum content of the steel is less than 0.0080 %, in
weight.

6. Process according to any one of the above claims, in which at the
continuous casting the steel temperature is from 20 to 30 °C higher
than its solidification temperature.

7. Process according to any one of the above claims, in which the
cast steel completely solidifies in 40-100 s.

8. Process according to any one of the above claims, in which the
solidified steel coming out from the mould is cut in slabs maintained
for 1 to 15 min at a temperature comprised, within 25 °C, between 1100
and 1250 °C.
9. Process according to any one of the above claims, in which during the hot rolled strip annealing before the cold rolling the strip undergoes a limited decarburization having a depth comprised between 10 and 35% of the strip thickness.

10. Process according to any one of the above claims, in which during the decarburization annealing the temperature is comprised between 800 and 900 °C, while during the heating a temperature of 750 °C is reached in a time of between 1 and 80 s.

11. Process according to claim 10, in which the treatment temperature is comprised between 830 and 880 °C while during the heating a temperature of 750 °C is reached in a time of between 4 and 60 s.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 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)

IPC 6 C21D

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 practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Patent family members are listed in annex.

* Special categories of cited documents:

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*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

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*"K* document member of the same patent family

Date of the actual completion of the international search

10 February 1998

Date of mailing of the international search report

04.03.98

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk
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