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54 **Non-oriented electrical steel sheet having a low watt loss and a high magnetic flux density and a process for producing the same.**

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Description

The present invention relates to a non-oriented electrical steel material having a low watt loss and a high magnetic flux density, and to a process for producing the same. Although throughout this specification and claims specific reference is made to the steel material being in sheet form, other geometric forms of the material may, of course, be used according to requirements.

A non-oriented electrical steel sheet is used as core material for electrical machinery and apparatuses, such as motors and transformers.

Recently, the demands for electrical machinery and apparatuses having enhanced characteristics have been increasing since, internationally, industry has been attempting to reduce electric power consumption and energy consumption in general. In respect to this, a low watt loss and a high magnetic flux density of the core material are indispensable for reducing electric power and energy consumption in electrical machinery and apparatuses. Also, recently, there have been very strong demands for the development of core material which can be used especially for medium and small sized electrical machinery and apparatuses and by which a low watt loss is attained, while at the same time maintaining the meritoriously a high magnetic flux density, and a low cost of a non-oriented electrical steel sheet. In order to meet such demands, the magnetic properties of a non-oriented electrical steel sheet must be improved so that the watt loss in terms of $W_{15/50}$ is 4.5 w/kg or less, while the magnetic flux density in terms of B_{50} is 1.71 Tesla or more.

As is well known, non-oriented electrical steel sheets are graded in accordance with the watt loss and magnetic flux density from S60- to S9-grades according to a JIS standard. In conventional high-grade non-oriented electrical steel sheets, the content of silicon which appreciably increases resistivity, is high so as to decrease the watt loss. For instance, the silicon content of a grade S60 is virtually 0%, and the silicon contents of S23, S18, and S9 grades are approximately 1.5%, approximately 2.0%, and approximately 3.0%, respectively. However, a high silicon content results in a decrease in the magnetic flux density.

The prior art is further described with reference to Figure 1 which illustrates relationships between the watt loss in terms of $W_{15/50}$ and the magnetic flux density B_{50} with regard to conventional non-oriented electrical steel sheets as well as a non-oriented electrical steel sheet according to the present invention.

The curves 1, and 1' in Fig. 1 represent the upper and lower limits of the B_{50} and $W_{15/50}$ of conventional non-oriented electrical steel sheets which are explained hereinafter, and illustrate that the watt loss is decreased in accordance with an increase in the magnetic flux density. Symbol 2 in Fig. 1 is the lines connecting the magnetic properties of non-oriented electrical steel sheets stipulated in JIS Standard C2552.

Attempts to improve the magnetic properties of a non-oriented electrical steel sheet, which does not rely on increasing the content of silicon have been made previously. That is, these attempts include devising a steel chemistry, e.g., the addition of aluminum or boron to silicon steel, or decreasing the carbon or sulfur content, as well as improving production conditions, i.e. employing a high-temperature annealing or a high reduction degree of cold rolling which is carried out before the final annealing. For instance, Japanese Unexamined Patent Publication No. 54-163720/79 of the present applicant (Nippon Steel Corporation) discloses the addition boron into silicon steel in such an amount that the weight ratio of the boron content/nitrogen content is maintained within a predetermined range. The growth of crystal grains during annealing is promoted due to the addition of boron, resulting in the economic production of economically a non-oriented electrical steel sheet having a low watt loss. Although the addition of boron disclosed in Japanese Unexamined Patent Publication No. 54163720/79 results in decrease in watt loss the relationship between the watt loss and the magnetic flux density falls within the curves 1 and 1' in Fig. 1. The addition of boron is therefore unsatisfactory for meeting the recent demands for improving the magnetic properties of non-oriented electrical steel sheet as compared that indicated by the line 3. USP No. 4,293,336 discloses the addition of tin into silicon steel so as to decrease the watt loss. Japanese Unexamined Patent Publication (Kokai) No. 56-102520 proposes a method for producing non-oriented silicon steel sheet with low watt loss due to adding Sn. However, in order for tin to effectively decrease the watt loss, it is necessary to carry out slow cooling during the annealing of a hot-rolled steel strip or employ a slow heating rate during the final annealing, which procedure disadvantageously limits to the process for producing a non-oriented electrical steel sheet. Although the addition of tin disclosed in Japanese Unexamined Patent Publication (Kokai) No. 56—102520 results in decrease in a watt loss, the relationship between the watt loss and magnetic flux density falls within the curves 1 and 1' of Fig. 1. Thus, the addition of tin is unsatisfactory for meeting the above-mentioned recent demands for improving the magnetic properties of a non-oriented electrical steel sheet.

It is an object of the present invention to provide a non-oriented electrical steel sheet, in which in the production thereof the watt loss in terms of $W_{15/50}$ is 4.5 w/kg at the highest and the magnetic flux density in terms of B_{50} is 1.71 Tesla at the lowest, that is, the relationship between $W_{15/50}$ and B_{50} is at least equal to the line 3 in Fig. 1.

It is another object of the present invention to provide a process for producing a non-oriented electrical steel sheet having the watt loss and magnetic flux density as specified above.

According to a discovery made by the present inventors, an increase in the magnetic flux density is non-oriented electrical steel sheets as compared with conventional non-oriented electrical steel sheets containing either tin or boron can be achieved by: adding boron into silicon steel in such an amount that

the weight ratio of the boron content/nitrogen content be maintained within a predetermined range; adding tin into silicon steel in a small amount; and, subjecting a hot-rolled steel strip to an annealing or carrying out a self-annealing by means of coiling a hot-rolled steel strip at a high temperature. That is, although the known addition of either boron or tin alone does not provide the magnetic flux density increased but only provides the watt loss to be decreased, the combined addition of boron and tin can simultaneously attain both low watt loss and high magnetic flux density.

According to another discovery made by the present inventors, the boron can be totally or partially replaced with aluminum when content of manganese in a silicon steel is appreciably high.

According to another discovery made by the present inventors, when silicon steel contains both boron and tin, the annealing mentioned above of a hot-rolled steel strip as well as a finishing annealing of a cold rolled steel strip can be carried out continuously in a short period of time.

The present invention was completed based on this discovery.

A non-oriented electrical steel sheet, according to the present invention having a low watt loss and a high magnetic flux density consists of 0.015% of carbon at the highest, from 0.3% to 2.0% of silicon, from 0.005% to 0.10% of acid-soluble aluminum (hereinafter referred to as sol. Al), from 0.02% to 0.20% of tin, 0.007% of nitrogen at the highest, and 0.005% of boron at the highest, the weight ratio of boron content/nitrogen content being from 0.5 to 1.5, the balance being iron and unavoidable impurities, said non-oriented electrical sheet being produced by a process comprising an annealing of a hot-rolled steel strip. This non-oriented electrical steel sheet of the present invention is hereinafter referred to as the Sn-B non-oriented electrical steel sheet.

Another non-oriented electrical steel sheet, according to the present invention, having a low watt loss and a high magnetic flux density consists of 0.015% of carbon at the highest, from 0.3% to 2.0% of silicon, from more than 1.0% to 1.5% of manganese, from 0.02% to 0.20% of tin, and either (a) or (b): (a) from 0.005% to 0.10% of sol. Al and 0.007% of nitrogen at the highest, and 0.005% of boron at the highest, the weight ratio of boron content/nitrogen content being from 0.5 to 1.5; or, (b) from more than 0.1% to 0.2% of sol. Al, the balance being iron and unavoidable impurities, said sheet being produced by a process comprising the steps comprising an annealing of a hot-rolled steel strip. This sheet is hereinafter referred to as the Sn-Al (B) nonoriented electrical steel sheet.

A process for producing the Sn-B non-oriented electrical steel sheet or the Sn-Al(B) non-oriented electrical steel sheet according to the present invention successively comprises the steps of: hot-rolling a silicon steel which having the composition as specified above; annealing the hot-rolled steel strip; cold rolling the hot-rolled steel strip once, or twice or more with an intermediate annealing; and, continuously annealing the cold-rolled steel strip. The annealing of the hot-rolled steel strip may be carried out by means of coiling a hot-rolled steel strip at a temperature of 700°C at the lowest and then self-annealing the coiled hot-rolled steel strip. That is, instead of carrying out usual annealing, such as hot-coil annealing, after the steel is hot-rolled, annealing of the hot-rolled strip may be completed in the hot-rolling step. When the annealing of a hot-rolled strip is carried out after the hot-rolling step, the annealing temperature is 850°C at the lowest.

First, the Sn-B non-oriented electrical steel sheet is described with regard to how tin and boron synergistically improve the magnetic properties thereof. When a non-oriented electrical steel sheet contains boron only, the boron fixes nitrogen which is detrimental to the magnetic properties and boron nitrides precipitate in the crystal grains. When a non-oriented electrical steel sheet contains tin only, the tin segregates at the grain boundaries and suppresses during recrystallization the generation of a (111) orientation which orientation is detrimental to the magnetic properties thereof.

In the Sn-B non-oriented electrical steel sheet, the segregated tin suppresses the recrystallization to initiate at the grain boundaries and promotes recrystallization to initiate in the crystal grains. In addition, the boron nitrides which are precipitated in the crystal grains behave as nuclei during recrystallization and promotes the generation of (110) and (100) textures which are advantageous for the magnetic properties thereof. Therefore, the magnetic properties of the Sn-B non-oriented electrical steel sheet are considerably improved over the magnetic properties of a non-oriented electrical steel sheet containing either boron or tin alone.

Second, the Sn-Al(B) non-oriented electrical steel sheet is described with regard to how manganese, tin and aluminum or boron synergistically improve the magnetic properties thereof. Manganese lowers the recrystallization temperature and substantially facilitates the recrystallization. When the Sn-Al(B) non-oriented electrical steel sheet contains boron, the synergistic effect of tin and boron is explained with reference to the Sn-B non-oriented electrical steel sheet is also attained and promoted since manganese substantially promotes recrystallization.

When the Sn-Al(B) non-oriented electrical steel sheet contains an appreciable amount of sol. Al, i.e. from more than 0.1% to 0.2%, the improvement in magnetic properties is attained by even partially or totally replacing boron with sol. Al. Aluminum added to a silicon steel and alloyed in the silicon steel as sol. Al in an appreciable amount prevents the precipitation of AlN, which is detrimental to the magnetic properties thereof. In addition, aluminum increases the resistivity and decreases the watt loss of silicon steels. Tin segregates at the grain boundaries and suppresses during recrystallization the generation of (111) orientation which is detrimental to the magnetic properties of a silicon steel. Manganese, sol. Al, and tin which are advantageous for the magnetic properties as understood from the above description

synergistically promotes the generation of (110) and (100) orientations so that the Sn-Al(B) non-oriented electrical steel sheet has predominantly (110) and (100) textures.

It is to be noted with regard to nitrogen and sol. Al that: nitrogen does not form compounds or precipitates which behave as nuclei during recrystallization; AlN which is detrimental to the magnetic properties of a silicon steel is not formed due to an appreciable Sol. Al content of; and, sol. Al not only removes the detrimental effects of nitrogen but also increases resistivity, thereby decreasing the watt loss.

As will have been understood from the descriptions hereinabove, the concept which are common to both the Sn-B nonoriented electrical steel sheet and the Sn-Al(B) non-oriented electrical steel sheet is to controlling the recrystallization so that it is advantageous with regard to the magnetic properties thereof. When this concept is explained in more metallurgical terms, it can be said that the combined addition of tin together with boron and or sol. Al renders recrystallization liable to occur predominantly in the crystal grains, and (110) and (100) textures which are desirable for the magnetic are formed during recrystallization. On the other hand, conventional addition of tin only and addition of boron and/or sol. Al only are not very effective for suppressing the formation of (111) texture which is detrimental to the magnetic properties of a non-oriented electrical steel sheet.

The compositions of the Sn-B nonoriented electrical steel sheet and the SnB(Al) non-oriented electrical steel sheet are now described.

Carbon is a harmful element which increases the watt loss. Therefore, a low carbon content, i.e. 0.015% or less, is desirable so as to reduce the watt loss and prevent deterioration of the magnetic properties due to aging or the so-called magnetic aging. A carbon content of not more than 0.005% is desirable for promoting the synergistic effects which are attained by combined addition of tin with boron and/or sol. Al.

Silicon increases the resistivity and decreases the watt loss of a steel as is well known. Silicon content which is effective for decreasing the watt loss is 0.3% at the lowest. However, when the silicon content is more than 2.0%, the rolling workability of silicon steel is impaired and the nonoriented electrical steel sheet becomes expensive.

Aluminum is necessary for deoxidizing steels. A sol. Al content of 0.005% is necessary for effectively deoxidizing silicon steels.

In the case of the Sn-B non-oriented electrical steel sheet and the Sn-Al(B) non-oriented silicon steel sheet containing boron, the maximum content of sol. Al should be so controlled that sol. Al does not excessively fix the nitrogen. If the sol. Al content is more than 0.1%, the sol. Al fixes the nitrogen excessively, and thus the amount of solute boron is increased with the result that the watt loss is increased and the magnetic flux density is decreased. In other words, when the sol. Al content is more than 0.1%, sol. Al renders the boron ineffective for improving the magnetic properties of the non-oriented electrical steel sheet.

In the case of the Sn-Al(B) non-oriented electrical steel sheet, boron can be partially or totally replaced with sol. Al as described above. If boron is totally replaced with sol. Al, the sol. Al content must be more than 0.1% so as to prevent the precipitation of AlN. If boron is partially replaced with sol. Al and if the content of sol. Al is 0.1% at the highest, the weight ratio of the boron content/nitrogen content should be from 0.5 to 1.5 ($0.5 \leq B/N \leq 1.5$). When the content of sol. Al is more than 0.20%, the magnetic flux density is low.

Boron together with tin or together with both manganese and tin synergistically improves the magnetic properties of a non-oriented electrical steel sheet. In order for boron to have a synergistic effect, the weight ratio of the boron content/nitrogen content must be from 0.5 to 1.5. If the weight ratio is less than 0.5, it is difficult to eliminate the detrimental effect of nitrogen. On the other hand, when such ratio is more than 1.5, an amount of solute boron is so increased that the magnetic properties of the non-oriented electrical steel sheet cannot be improved. The boron content must be 0.005% at the highest so as to prevent that cracks are formed on slabs during hot rolling.

Tin together with boron, or together with both manganese and sol. Al synergistically improve the magnetic properties of the non-oriented electrical steel sheet. In order for tin to have a synergistic effect, the content of tin must be 0.02% at the lowest. However, when the tin content is more than 0.20%, the effect of tin is saturated and the production cost is increased.

Manganese is not conventionally used to enhance the magnetic properties of a non-oriented electrical steel sheet because manganese is liable to form nonmetallic inclusions, such as sulfides and oxides. However, it is possible to use manganese to enhance the magnetic properties of an electrical steel sheet since the steelmaking technique is advanced enough so that high-purity steels can be produced. According to a discovery made by the present inventors manganese is effective for developing (100) and (110) textures, which textures result in desirable magnetic properties, and for suppressing a (111) texture, which texture is detrimental to the magnetic properties thereof. In the Sn-Al(B) nonoriented electrical steel sheet the manganese content is more than 1.0% so as to promote development of (100) and (110) textures. And, since manganese lowers the ferrite-austenite transformation temperature, if the manganese content is more than 1.5%, ferrite-austenite transformation is likely to occur during the annealing of a hot-rolled strip, thereby rendering the manganese ineffective for improving the texture and the magnetic properties. The manganese content in the Sn-B non-oriented electrical steel sheet is not specified and may be less than 1.0%, e.g. approximately 0.3%.

The elements other than those described above are iron and unavoidable impurities.

The Sn-B non-oriented electrical steel sheet and a process for producing such a sheet are further described with reference to experiments carried out by the present inventions.

In the experiments, four hot-rolled steel strips having the compositions as given in Table 1-1, below, were subjected to each of the production steps given in Table 1-2, below. The magnetic properties obtained are given in Table 1-3, below.

TABLE 1-1
Composition of steels (%)

No.	C	Si	S	Sol. Al	B	N	Sn
1	0.003	1.50	0.005	0.023	0.0021	0.0018	0.065
2	0.003	1.51	0.004	0.022	0.0022	0.0017	—
3	0.003	1.38	0.004	0.260	—	0.0018	—
4	0.003	1.40	0.005	0.255	—	0.0018	0.070

TABLE 1-2

Process A	Hot-rolled strip	Annealing 900°C×2 min.	Cold-rolling 0.5 mm	Continuous annealing 900°C×20"
Process B	Hot-rolled strip	Annealing 900°C×2 min.	Cold-rolling 0.5 mm	Continuous annealing 900°C×20"

TABLE 1-3
Magnetic properties

Composition & process	$W_{15/50}$ W/kg	B_{50} Tesla	Composition & process	$W_{15/50}$ W/kg	B_{50} Tesla
1A	3.58	1.754	1B	4.01	1.701
2A	3.84	1.684	2B	4.32	1.663
3A	3.98	1.686	3B	4.36	1.673
4A	3.67	1.704	4B	4.25	1.686

As can be seen from Table 1-3, only the Sn-B non-oriented electrical steel sheet, i.e. the symbol 1A, had a low watt loss and a high magnetic flux density. Other symbols, i.e., non-oriented electrical steel sheets, in which at least either the combined addition of tin and boron, or annealing of a hot-rolled strip, had a high watt loss and a low magnetic flux density is not satisfied.

The process for producing the Sn-B non-oriented electrical steel sheet and the Sn-Al(B) non-oriented electrical steel sheet is now described.

Steels having the composition as described above are melted in a converter, an electric furnace, or the like, and are continuously cast or cast as an ingot, followed by rough rolling to obtain a slab.

The slab is hot-rolled at a predetermined temperature so as to produce a hot-rolled steel strip. Annealing of a hot-rolled steel strip can improve the texture of the strip, thereby enhancing the magnetic properties thereof as compared with those without annealing of a hot-rolled strip. If the hot-rolled strip is annealed at a temperature less than 850°C, the annealing is not very effective for improving the texture of the strip.

Annealing of the hot-rolled steel strip may be carried out by means of self-annealing, in which the strip is annealed by the heat retained therein. The self-annealing can be attained by coiling a hot-rolled steel strip at a temperature of 700°C at the lowest. If the coiling temperature is less than 700°C, fine precipitates form during a subsequent annealing, i.e. the annealing of a hot-rolled steel strip, and suppress the growth of crystal grains.

A coiled hot-rolled strip is advantageously covered with a heat-insulation cover which reduces the amount of heat which radiates from the strip. Evidently, if the coiling temperature is less than 700°C, the hot-rolled steel strip is subsequently annealed, e.g. by means of the batch annealing or continuous annealing. Since the magnetic properties obtained by both rapid heating- and cooling-rates of annealing are excellent, the continuous annealing is advisable for annealing a hot-rolled steel strip.

A hot-rolled steel strip is then cold-rolled once or twice or more with an intermediate annealing, thereby obtaining a final thickness. The intermediate annealing is carried out between successive cold-rollings.

Finishing annealing of a cold-rolled steel strip is then carried out. Slow heating during the finishing annealing is not very advantageous for the magnetic properties, since the combined addition of tin with boron and/or sol. Al changes the influences of the heating rate upon the magnetic properties in such a manner that a rapid heating is rather desirable for the magnetic properties. The annealing temperature is varied in accordance with the magnetic properties to be attained. Since the continuous finishing annealing is more advisable than the batch finishing annealing, the production efficiency of the Sn-B non-oriented electrical steel sheet and Sn-Al(B) non-oriented electrical steel sheet is high, which is one of the synergistic effects attained by the combined addition of tin with boron and/or sol. Al.

Although the process for producing the Sn-B non-oriented electrical steel sheet and the Sn-Al(B) non-oriented electrical steel sheet is completed at the finishing annealing, such sheets may be further subjected to stress-relief annealing or skin pass rolling. The reduction rate (draft) at skin pass rolling depends on the intermediate annealing temperature. Preferably, reduction rate at skin-pass rolling is from 2% to 10%. A skin-pass rolled steel strip is then subjected to blanking to obtain a predetermined sheet section and is then stress-relief annealed. In this case, the so-called semi-processed non-oriented electrical steel sheet is produced. When the reduction rate at skin pass rolling, is less than 2%, stress-relief annealing is ineffective for improving the watt loss. On the other hand, a reduction rate at skin pass rolling of more than 10% results in deterioration the magnetic properties.

The present invention is described now by way of examples.

Example 1

Non-oriented electrical steel sheets were produced under the conditions of process for treating steels given in Table 2.

TABLE 2

Steel Nos.	Composition of slabs										Process conditions					Magnetic properties			
	C	Si	Mn	S	Al	B	Sn	N	B/N	CT	SA	HCA	T	FA	W 15/50 (W/kg)	B50 (Tesla)	W 15/50 (W/kg)	B50 (Tesla)	Remarks
																FA			
5	0.003	0.46	0.26	0.006	0.022	0.0022	0.07	0.0019	1.2	780°C	Effectuated	—	0.5 mm	875°C×20 sec.	4.41	1.79	4.19	1.79	Invention
6	0.003	0.47	0.24	0.007	0.023	0.0023	0.07	0.0020	1.2	650°C	—	—	0.5 mm	875°C×20 sec.	6.88	1.75	6.47	1.74	Control
7	0.003	0.52	0.31	0.006	0.031	0.0024	—	0.0021	1.1	790°C	Effectuated	—	0.5 mm	900°C×60 sec.	5.03	1.76	4.78	1.76	Control
8	0.003	1.13	0.28	0.006	0.025	0.0024	0.06	0.0020	1.2	800°C	Effectuated	—	0.5 mm	900°C×20 sec.	3.98	1.77	3.27	1.77	Invention
9	0.003	1.12	0.22	0.005	0.023	0.0023	0.06	0.0021	1.1	650°C	—	—	0.5 mm	900°C×20 sec.	4.72	1.69	4.02	1.69	Control
10	0.003	1.09	0.26	0.006	0.270	—	0.05	0.0019	—	650°C	—	900°C×2 min.	0.5 mm	900°C×30 sec.	4.52	1.70	3.88	1.69	Control
11	0.003	1.67	0.27	0.004	0.023	0.0024	0.07	0.0021	1.1	670°C	—	925°C×2 min.	0.5 mm	900°C×20 sec.	3.38	1.75	2.86	1.75	Invention
12	0.002	1.69	0.30	0.004	0.022	0.0025	0.07	0.0023	1.1	660°C	—	—	0.5 mm	900°C×20 sec.	3.98	1.70	3.51	1.69	Control
13	0.003	1.72	0.22	0.005	0.025	0.0021	—	0.0019	1.1	660°C	—	925°C×2 min.	0.5 mm	900°C×20 sec.	3.76	1.68	3.34	1.68	Control
14	0.003	0.51	1.31	0.004	0.022	0.0024	0.07	0.0023	1.0	780°C	Effectuated	—	0.5 mm	875°C×20 sec.	3.95	1.81	3.48	1.80	Invention
15	0.003	0.50	1.30	0.004	0.18	—	0.06	0.0023	—	780°C	Effectuated	—	0.5 mm	875°C×20 sec.	3.89	1.81	3.41	1.80	Invention

CT ... Coiling temperature SA ... Self-annealing HCA ... Hot-coil annealing FA ... Finishing annealing SRA ... Stress-relief annealing

As can be understood from Table 2, both a low watt loss and a high magnetic flux density are attained when steels contain both boron and tin or has high manganese and sol. Al contents and contains tin, and at the same time these steels are self-annealed or annealed after the hot-rolling step.

5 Example 2

Steel Nos. 5, 6, 7, 14, and 15, were subjected to the same production procedure as in Example 1, except that virtually 0.5 mm thick cold-rolled steel strips were continuously annealed at 750°C for the period of 60 seconds (1 minute) and then skin-passes rolled at the reduction rate of 4%. An Epstein specimen was cut from the skin-pass rolled strip and the magnetic properties were measured after carrying out a stress-relief

10 annealing at 790°C for the period of 1 hour (60 minutes).

The magnetic properties are given in Table 3.

TABLE 3
Magnetic properties of semi-processed non-oriented electrical sheets

Steel Nos.	$W_{15/50}$ (W/kg)	B_{50} (Tesla)
5	3.95	1.75
6	6.23	1.73
7	4.53	1.73
14	2.92	1.79
15	2.89	1.78

Example 3

30 Steels having the composition as given in Table 4, below were subjected to continuously annealing hot-rolling, coiling at 750°C, annealing at 900°C for the period of 2 minutes, cold-rolling, to obtain 0.50 mm thick strips, finishing annealing at 850°C for the period of 1 minute, skinpass rolling with reduction degree of 6%; and, stress-relief annealing at 790°C for the period of 1 hour in 100% N_2 atmosphere.

TABLE 4
Composition of steels (%)

No.	C	Si	Mn	S	Sol. Al	Sn	N	B	B/N
16	0.004	0.49	0.26	0.003	0.026	—	0.0023	0.0024	1.0
17	0.004	0.51	0.50	0.002	0.022	—	0.0022	0.0022	1.0
18	0.003	0.46	0.77	0.002	0.028	—	0.0024	0.0023	1.0
19	0.004	0.47	1.03	0.003	0.024	—	0.0021	0.0025	1.2
20	0.003	0.53	1.27	0.002	0.022	—	0.0019	0.0023	1.2
21	0.004	0.50	0.28	0.003	0.027	0.09	0.0022	0.0020	0.9
22	0.003	0.49	0.52	0.003	0.030	0.10	0.0024	0.0025	1.0
23	0.003	0.49	0.79	0.003	0.021	0.09	0.0019	0.0022	1.2
24	0.003	0.51	1.04	0.002	0.024	0.11	0.0022	0.0022	1.0
25	0.004	0.47	1.27	0.002	0.027	0.10	0.0023	0.0026	1.1

The dependence of the magnetic properties upon the manganese content is illustrated in Figure 2. As will be understood from Fig. 2 a manganese content of more than 1% is effective for improving the magnetic properties of non-oriented electrical steel sheets containing tin and boron at such contents as providing $0.5 \leq B/N \leq 1.5$ and a decrease in the watt-loss and an increase in magnetic flux density are simultaneously attained.

Claims

1. A non-oriented electrical steel material having a low watt loss and a high magnetic flux density consisting of 0.015% of carbon at the highest, from 0.3 to 2.0% of silicon, from 0.005 to 0.10% of acid-soluble aluminium, from 0.02% to 0.20% of tin, 0.007% of nitrogen at the highest, and 0.005% of boron at the highest, the weight ratio of boron content/nitrogen content being from 0.5 to 1.5, the balance being iron and unavoidable impurities, said non-oriented electrical material being produced by a process comprising annealing after hot-rolling the steel material.
2. A non-oriented electrical steel sheet having a low watt loss and a high magnetic flux density according to the present invention, contains 0.015% of carbon at the highest, from 0.3% to 2.0% of silicon, from more than 1.0% to 1.5% of manganese, from 0.02% to 0.20% of tin, and either (a) or (b): (a) from 0.005% to 0.10% of acid-soluble aluminium and 0.005% of boron at the highest, 0.007% of nitrogen at the highest, the weight ratio of boron content/nitrogen content being from 0.5 to 1.5, or, (b) from more than 0.1% to 0.2% of acid-soluble aluminium, the balance being iron and unavoidable impurities, said sheet being produced by the steps comprising annealing after hot-rolling the steel material.
3. A process for producing a non-oriented electrical steel sheet according to claim 1 or 2 successively comprises the steps of: hot-rolling a silicon steel which has the composition as specified above; annealing after hot-rolling the steel material; cold rolling said hot-rolled steel material once or twice or more with an intermediate annealing; and, continuously annealing cold-rolled steel material.
4. A process according to claim 3, wherein the material is in strip form.
5. A process according to claim 3 or claim 4, wherein said annealing of the hot-rolled steel strip is carried out by means of coiling a hot-rolled steel strip at a temperature of 700°C at the lowest and self annealing the coiled hot-rolled steel strip.
6. A process according to claim 3 or claim 4 wherein said annealing of the hot-rolled strip is carried out after the hot-rolling step at a temperature of 850°C at the lowest.
7. A process according to claim 3 or claim 4, wherein said continuously annealed cold rolled steel strip is further subjected to a skin-pass rolling at a reduction rate of from 2 to 10%.

Patentansprüche

1. Nicht-orientierter Elektro Stahl mit niedrigem Wattverlust und hoher magnetischer Flußdichte, bestehend aus höchstens 0,015% Kohlenstoff, 0,3 bis 2,0% Silicium, 0,005 bis 0,10% säurelösliches Aluminium, 0,02 bis 0,20% Zinn, höchstens 0,007% Stickstoff und höchstens 0,005% Bor, wobei das Gewichtsverhältnis des Borgehalts zum Stickstoffgehalt 0,5 bis 1,5 beträgt, Rest Eisen und unvermeidbare Verunreinigungen, wobei der nicht-orientierte Elektro Stahl durch ein Verfahren hergestellt wird, das ein Glühen nach dem Warmwalzen des Stahls umfaßt.
2. Nicht-orientiertes Elektro Stahlblech mit niedrigem Wattverlust und hoher magnetischer Flußdichte gemäß vorliegender Erfindung, enthaltend höchstens 0,015% Kohlenstoff, 0,3 bis 2,0% Silicium, von mehr als 1,0 bis 1,5% Mangan, von 0,02 bis 0,20% Zinn, und entweder (a) oder (b): (a) von 0,005 bis 0,10% säurelösliches Aluminium, höchstens 0,005% Bor, und höchstens 0,007% Stickstoff, wobei das Gewichtsverhältnis des Borgehalts zum Stickstoffgehalt 0,5 bis 1,5 beträgt, oder (b) von mehr als 0,1 bis 0,2% säurelösliches Aluminium, Rest Eisen und unvermeidbare Verunreinigungen, wobei das Blech durch Verfahrensstufen hergestellt wird, die ein Glühen nach dem Warmwalzen des Stahls umfassen.
3. Verfahren zur Herstellung eines nicht-orientierten Elektro Stahlblechs nach den Ansprüchen 1 oder 2, umfassend nacheinander die Stufen: Warmwalzen eines Siliciumstahls mit der vorstehend angegebenen Zusammensetzung; Glühen nach dem Warmwalzen des Stahls; einmal, zweimal oder mehrmals Kaltwalzen des warmgewalzten Stahls mit einem Zwischenglühen; und Durchlaufglühen des kaltgewalzten Stahls.
4. Verfahren nach Anspruch 3, wobei das Material in Bandform vorliegt.
5. Verfahren nach Anspruch 3 oder 4, wobei das Glühen des warmgewalzten Stahlbandes durch Aufwickeln des warmgewalzten Stahlbandes bei einer Temperatur von mindestens 700°C und Glühen des aufgewickelten warmgewalzten Stahlbandes durchgeführt wird.
6. Verfahren nach Anspruch 3 oder 4, wobei das Glühen des warmgewalzten Stahlbandes nach dem Warmwalzschritt bei einer Temperatur von mindestens 850°C durchgeführt.
7. Verfahren nach Anspruch 3 oder 4, wobei das durchlaufgeglühte kaltgewalzte Stahlband ferner einem Kaltnachwalzen mit einer Dickenverminderung von 2 bis 10% unterzogen wird.

Revendications

1. Matériau en acier magnétique non-orienté ayant une faible perte en watts et une densité de flux magnétique élevée, consistant en au plus 0,015% de carbone, de 0,3 à 2,0% de silicium, de 0,005 à 0,10% d'aluminium soluble dans les acides, de 0,02 à 0,20% d'étain, d'au plus 0,007% d'azote et au plus 0,005% de bore, le rapport pondéral entre la teneur en bore et la teneur en azote étant de 0,5 à 1,5, le reste étant du fer et des impuretés inévitables, le matériau magnétique non-orienté étant produit par un procédé comprenant un recuit après laminage à chaud du matériau acier.
2. Tôle d'acier magnétique non-orienté ayant une faible perte en watts et une densité de flux

magnétique élevée selon la présente invention, qui contient 0,015% de carbone au plus, de 0,3% à 2,0% de silicium, de plus de 1,0% à 1,5% de manganèse, de 0,02% à 0,20% d'étain, et soit (a), soit (b): (a) de 0,005% à 0,10% d'aluminium soluble dans les acides et 0,005% de bore au plus, 0,007% d'azote au plus, le rapport pondéral entre la teneur en bore et la teneur en azote étant de 0,5 à 1,5, ou bien (b) de plus de 0,1% à 0,2% d'aluminium soluble dans les acides, le reste étant du fer et des impuretés inévitables, ladite tôle étant
5 produite par les étapes consistant en un recuit après laminage à chaud du matériau acier.

3. Procédé pour la fabrication d'une tôle d'acier magnétique non-orienté selon la revendication 1 ou 2, qui comprend successivement les étapes consistant à laminier à chaud un acier au silicium ayant la composition spécifiée ci-dessus; à recuire le matériau acier après laminage à chaud, à laminier à froid le
10 matériau acier laminé à chaud une fois, ou deux fois, ou plus, avec un recuit intermédiaire; et à recuire en continu le matériau acier laminé à froid.

4. Procédé selon la revendication 3, dans lequel le matériau se présente sous la forme d'une bande.

5. Procédé selon la revendication 3 ou la revendication 4, dans lequel le recuit de la bande d'acier laminée à chaud est effectué au moyen d'un bobinage d'une bande d'acier laminée à chaud à une
15 température d'au moins 700°C, avec un auto-recuit de la bande d'acier laminée à chaud et enroulée.

6. Procédé selon la revendication 3 ou la revendication 4, dans lequel le recuit de la bande laminée à chaud est effectué après l'étape de laminage à chaud à une température d'au moins 850°C.

7. Procédé selon la revendication 3 ou la revendication 4, dans lequel la bande d'acier laminée à froid et recuite en continu est soumise en outre à une passe de laminage à froid de finition avec un taux de
20 réduction de 2 à 10%.

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Fig. 1

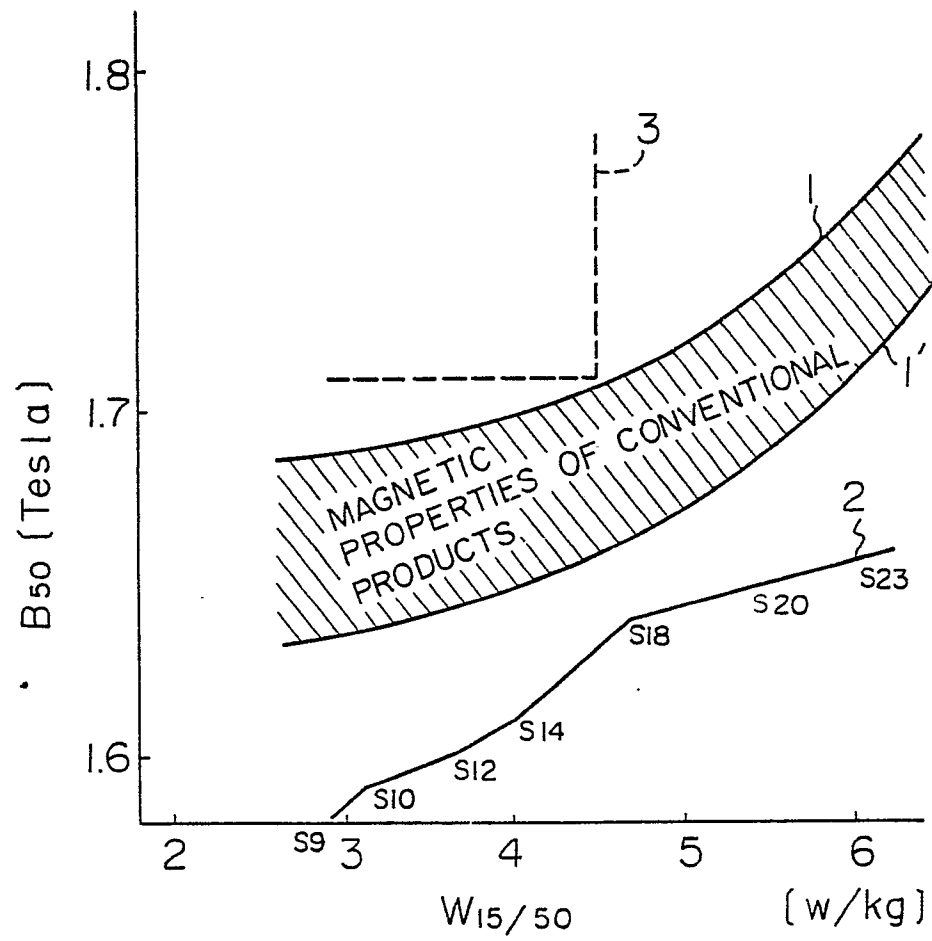


Fig. 2