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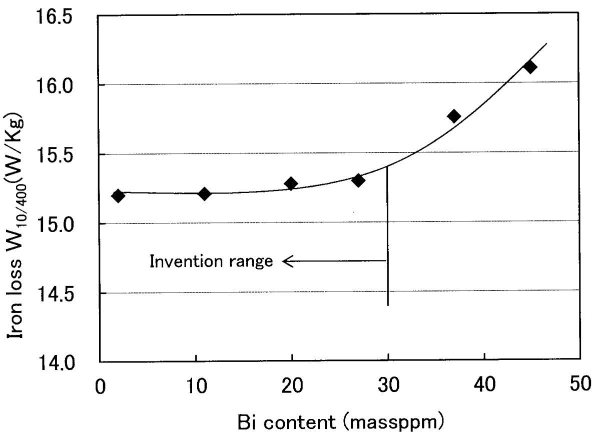
(54) NON-ORIENTED MAGNETIC STEEL SHEET WITH EXCELLENT HIGH FREQUENCY IRON LOSS CHARACTERISTICS

(57) A non-oriented electrical steel sheet has a chemical composition comprising C: not more than 0.005%, Si: 1.5-4%, Mn: 1.0-5%, P: not more than 0.1%, S: not more than 0.005%, Al: not more than 3 mass%, N: not more than 0.005 mass%, Bi: not more than 0.0030% as mass% and the remainder being Fe and inevitable impurities or a chemical composition containing C: not more than 0.005%, Si: 1.5-4%, Mn: 1.0-5%, P: not more than 0.1%, S: not more than 0.005%, Al: not more than 3 mass%, N: not more than 0.005 mass%, Bi: not more than 0.0030% and further one or two of Ca: 0.0005-0.005% and Mg: 0.0002-0.005%, and is stably excellent in the high-frequency iron loss property even if a great amount of Mn is included.

FIG. 2



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Description

TECHNICAL FIELD

[0001] This invention relates to a non-oriented electrical steel sheet having an excellent high-frequency iron loss property.

RELATED ART

[0002] A motor for a hybrid car or an electric car is driven at a high frequency region of 400-2 kHz from a viewpoint of miniaturization and high efficiency. A non-oriented electrical steel sheet used in a core material for such a high-frequency motor is desired to be low in the iron loss at a high frequency.

[0003] In order to reduce the iron loss at a high frequency, it is effective to decrease a sheet thickness and increase a specific resistance. In the method of decreasing the sheet thickness, however, not only the handling becomes difficult due to the decrease of rigidity in the materials but also the number of punching steps or lamination steps is increased, so that there is a problem of deteriorating the productivity. On the contrary, the method of increasing the specific resistance does not have the above disadvantage, so that it can be said to be desirable as a method for reducing a high-frequency iron loss.

[0004] The addition of Si is effective for increasing the specific resistance. However, Si is an element having a large solid-solution strengthening ability, so that there is a problem that the material is hardened with the increase of Si addition amount to deteriorate the rolling property. As one of means for solving the above problem, there is a method of adding Mn instead of Si. Since Mn is small in the solid-solution strengthening ability as compared to Si, the high-frequency iron loss can be reduced while suppressing the deterioration of the productivity.

[0005] As a technique of utilizing the above effect by Mn addition, for example, Patent Document 1 discloses a non-oriented electrical steel sheet containing Si: 0.5-2.5 mass%, Mn: 1.0-3.5 mass% and Al: 1.0-3.0 mass%. Also, Patent Document 2 discloses a non-oriented electrical steel sheet containing Si: not more than 3.0 mass%, Mn: 1.0-4.0 mass% and Al: 1.0-3.0 mass%.

PRIOR ART DOCUMENTS

PATENT DOCUMENTS

[0006]

Patent Document 1: JP-A-2002-47542
Patent Document 2: JP-A-2002-30397

SUMMARY OF THE INVENTION

TASK TO BE SOLVED BY THE INVENTION

[0007] However, the techniques disclosed in Patent Documents 1 and 2 have a problem that hysteresis loss is increased with the increase of Mn addition amount and hence the desired effect of reducing the iron loss may not be obtained.

[0008] The invention is made in consideration of the above problems inherent to the conventional art, and an object thereof is to provide a non-oriented electrical steel sheet having a stable and excellent high-frequency iron loss property even if a great amount of Mn is contained.

SOLUTION FOR TASK

[0009] The inventors have noted impurity ingredients contained in the steel sheet and made various studies for solving the above task. As a result, it has been found out that the deterioration of high-frequency iron loss property in high Mn-added steels is based on the presence of Bi included as an impurity and hence the high frequency iron loss can be reduced stably by suppressing Bi content even at a high Mn content, and the invention has been accomplished.

[0010] The invention is based on the above knowledge and is a non-oriented electrical steel sheet having a chemical composition comprising C: not more than 0.005 mass%, Si: 1.5-4 mass%, Mn: 1.0-5 mass%, P: not more than 0.1 mass%, S: not more than 0.005 mass%, Al: not more than 3 mass%, N: not more than 0.005 mass%, Bi: not more than 0.0030 mass% and the remainder being Fe and inevitable impurities.

[0011] The non-oriented electrical steel sheet according to the invention is characterized by containing one or two of

Ca: 0.0005-0.005 mass% and Mg: 0.0002-0.005 mass% in addition to the above chemical composition.

[0012] Also, the non-oriented electrical steel sheet according to the invention is characterized by further containing one or two of Sb: 0.0005-0.05 mass% and Sn: 0.0005-0.05 mass% in addition to the above chemical composition.

[0013] Further, the non-oriented electrical steel sheet according to the invention is characterized by further containing Mo: 0.0005-0.0030 mass% in addition to the above chemical composition.

[0014] Moreover, the non-oriented electrical steel sheet according to the invention is characterized by containing Ti: not more than 0.002 mass%.

EFFECT OF THE INVENTION

[0015] According to the invention, it is possible to produce a non-oriented electrical steel sheet having an excellent high-frequency iron loss property stably by suppressing a content of Bi included as an impurity even at a high Mn addition amount.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016]

FIG. 1 is a graph showing an influence of Bi content upon a relation between Mn content and high-frequency iron loss $W_{10/400}$.
FIG. 2 is a graph showing a relation between Bi content and high-frequency iron loss $W_{10/400}$.

EMBODIMENTS FOR CARRYING OUT THE INVENTION

[0017] At first, experiments building a momentum on the development of the invention will be described.

[0018] A steel containing C: 0.0016 mass%, Si: 3.35 mass%, P: 0.013 mass%, S: 0.0004 mass%, Al: 1.4 mass% and N: 0.0018 mass% and added with Mn changed within a range of 0.1-5.2 mass% is melted in a laboratory to form a steel ingot, which is hot rolled, subjected to a hot band annealing at 1000°C in an atmosphere of 100 vol% N_2 for 30 seconds, cold rolled to a cold rolled sheet of 0.30 mm in thickness and subjected to a final annealing at 1000°C in an atmosphere of 20 vol% H_2 - 80 vol% N_2 for 30 seconds.

[0019] In FIG. 1, symbol ● shows the above experimental results as a relation between Mn addition amount and iron loss $W_{10/400}$. As seen from these results, when Mn is less than 1 mass%, the iron loss is decreased with the increase of Mn addition amount, but the decrease of the iron loss become gentle at an amount of not less than 1 mass%, and rather the iron loss is increased at an amount exceeding 4 mass%. In order to investigate this cause, when the steel sheet containing 2 mass% of Mn is observed by TEM, granular Bi is found in grain boundaries.

[0020] In order to further investigate the influence of Bi upon the magnetic properties, a steel prepared by adding Mn variously changed within a range of 0.1-5.2 mass% to a high-purity steel containing C: 0.0014 mass%, Si: 3.33 mass%, Al: 1.2 mass%, P: 0.014 mass%, S: 0.0006 mass%, N: 0.0020 mass% and Bi: not more than 0.0010 mass% is melted in a laboratory and shaped into a cold rolled and annealed sheet in the same manner as in the above experiment to measure an iron loss $W_{10/400}$.

[0021] The thus obtained experimental results are shown by symbol A in FIG. 1. As seen from these results, the iron loss is reduced with the increase of Mn addition amount in the cold rolled and annealed sheet made from a high-purity steel having a decreased Bi content as compared to the steel sheet shown by symbol ●. When the steel sheet containing 2 mass% of Mn is observed by TEM, granular Bi is not found in the grain boundaries. From this fact, it is guessed that the increase of the iron loss associated with the increase of Mn addition amount in the steel sheet of symbol ● is based on the increase of hysteresis loss due to fine precipitation of Bi.

[0022] In the steel sheet containing less than 1 mass% of Mn, the effect of improving the iron loss by the decrease of Bi is found, but the ratio thereof is small. Although the reason is not clear sufficiently, it is considered that the driving force for grain growth is lowered by solute drag of Mn in the steels having an increased Mn amount, and hence the grain growth is easily and largely influenced by the presence of fine Bi.

[0023] In general, Bi is an impurity incorporated from the scrap, so that not only the amount incorporated but also the deviation thereof becomes gradually large associated with the increase of the scrap use ratio in recent years. Such an increase of Bi content is not a big problem in the electrical steel sheets having a low Mn content, but the steels having a high Mn content are considered to be largely influenced by a slight amount of Bi because the grain growth is lowered by solute drag of Mn.

[0024] In order to investigate the influence of Bi content on the iron loss, a steel prepared by adding Bi variously changed within a range of tr. to 0.0045 mass% to a steel containing C: 0.0022 mass%, Si: 3.20 mass%, Mn: 1.7 mass%, Al: 1.3 mass%, P: 0.014 mass%, S: 0.0005 mass% and N: 0.0020 mass% is melted in a laboratory and shaped into a cold rolled and annealed sheet of 0.30 mm in thickness in the same manner as in the above experiment to measure an iron loss $W_{10/400}$.

[0025] In FIG. 2 are shown the above experimental results as a relation between Bi content and iron loss $W_{10/400}$. As seen from this figure, the iron loss is largely decreased when the Bi content is not more than 0.0030 mass% (not more than 30 massppm). This is considered due to the fact that the grain growth is improved by decreasing Bi. From this fact, it is confirmed that the Bi content is necessary to be decreased to not more than 0.0030 mass% for suppressing the bad influence of Bi upon the grain growth. The invention is based on the above new knowledge.

[0026] There will be described the chemical composition in the non-oriented electrical steel sheet according to the invention below.

C: not more than 0.005 mass%

[0027] C is an element forming a carbide with Mn. When it exceeds 0.005 mass%, the amount of Mn-based carbide is increased to block the grain growth, so that an upper limit is 0.005 mass%. Preferably, it is not more than 0.002 mass%.

Si: 1.5-4 mass%

[0028] Si is an element effective for increasing a specific resistance of steel and reducing an iron loss and is added in an amount of not less than 1.5 mass%. While when it is added in an amount exceeding 4 mass%, the magnetic flux density is lowered, so that an upper limit is 4 mass%. Preferably, the lower limit of Si is 2.0 mass% and the upper limit thereof is 3.0 mass%.

Mn: 1.0-5 mass%

[0029] Mn is effective for increasing a specific resistance of steel and reducing an iron loss without largely damaging the workability and is an important ingredient in the invention, which is added in an amount of not less than 1.0 mass%. In order to further obtain an effect of reducing the iron loss, it is preferable to be added in an amount of not less than 1.6 mass%. While when it is added in an amount exceeding 5 mass%, the magnetic flux density is lowered, so that an upper limit is 5 mass%. Preferably, the lower limit of Mn is 2 mass% and the upper limit thereof is 3 mass%.

P: not more than 0.1 mass%

[0030] P is an element having a large solid-solution strengthening ability, but when it is added in an amount exceeding 0.1 mass%, the steel sheet is significantly hardened to deteriorate the productivity, so that it is limited to not more than 0.1 mass%. Preferably, it is not more than 0.05 mass%.

S: not more than 0.005 mass%

[0031] S is an inevitable impurity. When it is included in an amount exceeding 0.005 mass%, MnS is precipitated to block the grain growth and increase the iron loss, so that an upper limit is 0.005 mass%. Preferably, it is not more than 0.001 mass%.

Al: not more than 3 mass%

[0032] A1 is an element effective for increasing a specific resistance of steel and reducing an iron loss like Si. When it is added in an amount exceeding 3 mass%, the magnetic flux density is lowered, so that an upper limit is 3 mass%. Preferably, it is not more than 2 mass%. However, when Al content is less than 0.1 mass%, fine AlN is precipitated to block the grain growth and increase the iron loss, so that a lower limit is preferable to be 0.1 mass%.

N: not more than 0.005 mass%

[0033] N is an inevitable impurity penetrated from air into steel. When the content is large, grain growth is blocked due to the precipitation of AlN to increase the iron loss, so that an upper limit is restricted to 0.005 mass%. Preferably, it is not more than 0.003 mass%.

Bi: not more than 0.0030 mass%

[0034] Bi is an important element to be controlled in the invention because it badly affects the high-frequency iron loss property. When Bi content exceeds 0.0030 mass% as seen from FIG. 2, the iron loss violently increases. Therefore, Bi is restricted to not more than 0.0030 mass%. Preferably, it is not more than 0.0010 mass%.

[0035] The non-oriented electrical steel sheet according to the invention is preferable to contain one or two of Ca and Mg in addition to the above chemical composition.

Ca: 0.0005-0.005 mass%

[0036] Ca is an element effective for forming a sulfide and coarsening by compositely precipitating with Bi to suppress the adverse effect of Bi and reduce the iron loss. In order to obtain such an effect, it is preferable to be added in an amount of not less than 0.0005 mass%. However, when it is added in an amount exceeding 0.005 mass%, the amount of CaS precipitated becomes too large and the iron loss is increased adversely, so that an upper limit is preferable to be 0.005 mass%. More preferably, the lower limit of Ca is 0.001 mass% and the upper limit thereof is 0.004 mass%.

Mg: 0.0002-0.005 mass%

[0037] Mg is an element effective for forming an oxide and coarsening by compositely precipitating with Bi to suppress the adverse effect of Bi and reduce the iron loss. In order to obtain such an effect, it is preferable to be added in an amount of not less than 0.0002 mass%. However, the addition exceeding 0.005 mass% is difficult and brings about the increase of the cost, so that an upper limit is preferable to be 0.005 mass%. More preferably, the lower limit of Mg is 0.001 mass% and the upper limit thereof is 0.004 mass%.

[0038] Also, the non-oriented electrical steel sheet according to the invention is preferable to further contain the following ingredients in addition to the above chemical composition.

Sb: 0.0005-0.05 mass%, Sn: 0.0005-0.05 mass%

[0039] Sb and Sn have an effect of improving the texture to increase the magnetic flux density, so that they can be added in an amount of not less than 0.0005 mass% alone or in admixture. More preferably, it is not less than 0.01 mass%. However, the addition exceeding 0.05 mass% brings about the embrittlement of the steel sheet, so that an upper limit is preferable to be 0.05 mass%. More preferably, the lower limit of each of Sb and Sn is 0.01 mass% and the upper limit thereof is 0.04 mass%.

Mo: 0.0005-0.0030 mass%

[0040] Mo has an effect of coarsening the resulting carbide to reduce the iron loss and is preferable to be added in an amount of not less than 0.0005 mass%. However, when it is added in an amount exceeding 0.0030 mass%, the amount of the carbide becomes too large and the iron loss is rather increased, so that an upper limit is preferable to be 0.0030 mass%. More preferably, the lower limit of Mo is 0.0010 mass% and the upper limit thereof is 0.0020 mass%.

Ti: not more than 0.002 mass%

[0041] Ti is an element forming a carbonitride. When the content is large, the amount of the carbonitride precipitated becomes too large, so that the grain growth is blocked and the iron loss is increased. In the invention, therefore, Ti is preferable to be restricted to not more than 0.002 mass%. More preferably, it is not more than 0.001 mass%.

[0042] In the non-oriented electrical steel sheet according to the invention, the remainder other than the aforementioned ingredients is Fe and inevitable impurities. However, other elements may be included within a range not damaging the function effect of the invention.

[0043] Next, the production method of the non-oriented electrical steel sheet according to the invention will be described below.

[0044] In the method for producing the non-oriented electrical steel sheet according to the invention, conditions are not particularly limited except that the chemical composition of the steel sheet is controlled within a range defined in the invention, so that the production may be performed under the same conditions as in the normal non-oriented electrical steel sheet. For example, the steel sheet can be produced by a method wherein a steel having a chemical composition adapted to the invention is melted, for example, in a converter, a degassing device or the like and shaped into a raw steel material (slab) by a continuous casting method or an ingot making-blooming method, which is hot rolled, subjected to a hot band annealing as required and further to a single cold rolling or two or more cold rollings including an intermediate annealing therebetween to a predetermined sheet thickness and subsequently to a final annealing.

EXAMPLES

[0045] A steel having a chemical composition shown in Table 1 is melted in a converter, degassed by blowing and continuously cast into a slab, which is heated at 1100°C for 1 hour, hot rolled at a final rolling temperature of 800°C and wound into a coil at a temperature of 610°C to obtain a hot rolled sheet of 1.8 mm in thickness. Thereafter, the hot rolled sheet is subjected to a hot band annealing at 1000°C in an atmosphere of 100 vol% N_2 for 30 seconds and cold rolled to obtain a cold rolled sheet having a sheet thickness of 0.35 mm, which is subjected to a final annealing at 980°C in an atmosphere of 20 vol% H_2 - 80 vol% N_2 for 15 seconds to form a cold rolled and annealed sheet.

[0046] From the thus cold rolled and annealed sheet are cut out Epstein samples with a width: 30 mm x a length: 280 mm in the rolling direction and in a direction perpendicular to the rolling direction to measure an iron loss $W_{10/400}$ and a magnetic flux density B_{50} according to JIS C2550, respectively. These results are also shown in Table 1.

Table 1-1

№	Chemical composition (mass%)														Sheet thickness (mm)	Magnetic properties		Remarks
	C	Si	Mn	P	S	Al	N	Bi	Ca	Mg	Sb	Sn	Mo	Ti		Iron loss $W_{10/400}$ (W/kg)	Magnetic flux density B_{50}(T)	
1	0.0015	3.20	1.59	0.011	0.0003	1.20	0.0020	0.0002	tr.	tr.	tr.	tr.	0.0013	0.0002	0.35	15.20	1.67	Invention Steel
2	0.0012	3.12	1.59	0.011	0.0004	1.20	0.0015	0.0011	tr.	tr.	tr.	tr.	0.0008	0.0001	0.35	15.21	1.67	Invention Steel
3	0.0013	3.13	1.57	0.011	0.0003	1.16	0.0016	0.0020	tr.	tr.	tr.	tr.	0.0014	0.0002	0.35	15.28	1.67	Invention Steel
4	0.0015	3.14	1.56	0.011	0.0002	1.16	0.0016	0.0027	tr.	tr.	tr.	tr.	0.0015	0.0001	0.35	15.30	1.67	Invention Steel
5	0.0017	3.21	1.60	0.012	0.0003	1.15	0.0014	0.0037	tr.	tr.	tr.	tr.	0.0010	0.0002	0.35	15.76	1.68	Comparative Steel
6	0.0017	3.15	1.59	0.013	0.0004	1.18	0.0015	0.0045	tr.	tr.	tr.	tr.	0.0011	0.0002	0.35	16.11	1.68	Comparative Steel
7	0.0016	3.16	0.15	0.012	0.0003	1.17	0.0014	0.0002	tr.	tr.	tr.	tr.	0.0011	0.0003	0.35	16.00	1.69	Comparative Steel
8	0.0000	3.14	0.91	0.011	0.0003	1.16	0.0015	0.0001	tr.	tr.	tr.	tr.	0.0014	0.0002	0.35	15.70	1.68	Comparative Steel
9	0.0019	3.16	1.55	0.012	0.0004	1.16	0.0013	0.0003	tr.	tr.	tr.	tr.	0.0012	0.0001	0.35	15.30	1.68	Invention Steel
10	0.0022	3.22	2.51	0.013	0.0003	1.15	0.0014	0.0002	tr.	tr.	tr.	tr.	0.0010	0.0002	0.35	15.10	1.66	Invention Steel
11	0.0016	3.16	3.49	0.012	0.0003	1.18	0.0017	0.0003	tr.	tr.	tr.	tr.	0.0014	0.0002	0.35	15.04	1.65	Invention Steel
12	0.0014	3.15	4.43	0.014	0.0004	1.18	0.0016	0.0004	tr.	tr.	tr.	tr.	0.0013	0.0002	0.35	15.00	1.65	Invention Steel
13	0.0014	3.16	5.20	0.010	0.0004	1.17	0.0023	0.0003	tr.	tr.	tr.	tr.	0.0013	0.0002	0.35	15.02	1.61	Comparative Steel

(continued)

No	Chemical composition (mass%)														Sheet thickness (mm)	Magnetic properties		Remarks
	C	Si	Mn	P	S	Al	N	Bi	Ca	Mg	Sb	Sn	Mo	Ti		Iron loss $W_{10/400}$ (W/kg)	Magnetic flux density B_{50}(T)	
14	0.0014	3.14	<u>0.50</u>	0.013	0.0005	1.20	0.0019	0.0025	tr.	tr.	tr.	tr.	0.0009	0.0003	0.35	16.45	1.66	Comparative Steel
15	0.0013	3.15	1.53	0.012	0.0003	1.17	0.0017	0.0005	tr.	tr.	tr.	tr.	0.0008	0.0001	0.35	15.30	1.67	Invention Steel
16	0.0017	3.17	1.52	0.013	0.0003	1.18	0.0019	0.0003	tr.	tr.	0.0053	tr.	0.0014	0.0001	0.35	15..22	1.68	Invention Steel
17	0.0011	3.16	1.57	0.011	0.0004	1.20	0.0018	0.0003	tr.	tr.	0.0174	tr.	0.0012	0.0002	0.35	15.17	1.69	Invention Steel
18	0.0014	3.14	1.56	0.012	0.0003	1.20	0.0016	0.0005	tr.	tr.	tr.	0.0070	0.0010	0.0002	0.35	15.14	1.68	Invention Steel
19	0.0016	3.20	1.56	0.012	0.0004	1.16	0.0021	0.0004	tr.	tr.	tr.	0.0240	0.0008	0.0003	0.35	15.12	1.69	Invention Steel
20	0.0018	3.14	1.56	0.014	0.0004	1.21	0.0019	0.0003	tr.	tr.	tr.	0.0420	0.0007	0.0001	0.35	15.09	1.69	Invention Steel
21	0.0021	3.12	1.57	0.013	0.0003	1.20	0.0017	0.0005	0.0023	tr.	tr.	tr.	0.0014	0.0001	0.35	14.98	1.67	Invention Steel
22	0.0020	3.17	1.55	0.012	0.0004	1.21	0.0016	0.0015	0.0035	tr.	tr.	tr.	0.0013	0.0003	0.35	15.07	1.67	Invention Steel

Table 1-2

No	Chemical composition (mass %)														Sheet thickness (mm)	Magnetic properties		Remarks
	C	Si	Mn	P	S	Al	N	Bi	Ca	Mg	Sb	Sn	Mo	Ti		Iron loss $W_{10/400}$ (W/kg)	Magnetic flux density B_{50} (T)	
23	0.0021	3.13	1.56	0.012	0.0005	1.20	0.0017	0.0015	0.0047	tr.	tr.	tr.	0.0008	0.0002	0.35	15.20	1.67	Invention Steel
24	0.0016	3.14	1.54	0.013	0.0003	1.22	0.0018	0.0016	0.0060	tr.	tr.	tr.	0.0008	0.0002	0.35	15.70	1.67	Comparative Steel
25	0.0017	3.13	1.54	0.011	0.0003	1.21	0.0016	0.0035	0.0032	tr.	tr.	tr.	0.0015	0.0003	0.35	15.59	1.67	Comparative Steel
26	0.0015	3.18	1.53	0.012	0.0004	1.23	0.0015	0.0005	tr.	0.0014	tr.	tr.	0.0016	0.0002	0.35	14.98	1.67	Invention Steel
27	0.0016	3.19	1.54	0.011	0.0004	1.24	0.0021	0.0015	tr.	0.0015	tr.	tr.	0.0017	0.0002	0.35	15.08	1.67	Invention Steel
28	0.0014	3.22	1.57	0.012	0.0003	1.22	0.0020	0.0015	tr.	0.0041	tr.	tr.	0.0015	0.0001	0.35	15.07	1.67	Invention Steel
29	0.0013	0.88	1.52	0.030	0.0004	2.60	0.0025	0.0003	tr.	tr.	tr.	tr.	0.0013	0.0002	0.35	18.42	1.67	Comparative Steel
30	0.0015	3.14	1.53	0.012	0.0003	1.22	0.0017	0.0002	tr.	tr.	tr.	tr.	0.0001	0.0002	0.35	15.40	1.67	Invention Steel
31	0.0017	3.16	1.54	0.012	0.0003	1.23	0.0016	0.0003	tr.	tr.	tr.	tr.	0.0022	0.0002	0.35	15.36	1.68	Invention Steel
32	0.0016	3.18	1.56	0.012	0.0004	1.20	0.0017	0.0002	tr.	tr.	tr.	tr.	0.0028	0.0001	0.35	15.42	1.68	Invention Steel
33	0.0014	2.22	1.26	0.012	0.0003	2.18	0.0021	0.0005	tr.	tr.	tr.	tr.	0.0011	0.0003	0.35	15.23	1.67	Invention Steel
34	0.0016	3.55	1.20	0.004	0.0004	1.14	0.0021	0.0003	tr.	tr.	tr.	tr.	0.0012	0.0002	0.35	14.70	1.67	Invention Steel
35	0.0017	4.92	1.13	0.004	0.0003	0.32	0.0016	0.0003	tr.	tr.	tr.	tr.	0.0014	0.0002	0.35	14.62	1.60	Comparative Steel

(continued)

No	Chemical composition (mass %)														Sheet thickness (mm)	Magnetic properties		Remarks
	C	Si	Mn	P	S	Al	N	Bi	Ca	Mg	Sb	Sn	Mo	Ti		Iron loss $W_{10/400}$ (W/kg)	Magnetic flux density B_{50} (T)	
36	0.0015	2.79	1.58	0.013	0.0003	1.33	0.0017	0.0005	tr.	tr.	tr.	tr.	0.0013	0.0002	0.35	14.96	1.67	Invention Steel
37	0.0014	2.49	1.57	0.011	0.0004	2.44	0.0021	0.0005	tr.	tr.	tr.	tr.	0.0014	0.0001	0.35	14.78	1.66	Invention Steel
38	0.0018	1.52	1.58	0.012	0.0004	3.47	0.0022	0.0002	tr.	tr.	tr.	tr.	0.0013	0.0002	0.35	15.03	1.63	Comparative Steel
39	0.0013	2.79	1.56	0.013	0.0017	1.32	0.0014	0.0003	tr.	tr.	tr.	tr.	0.0013	0.0001	0.35	15.22	1.65	Invention Steel
40	0.0015	2.79	1.57	0.011	0.0055	1.32	0.0016	0.0002	tr.	tr.	tr.	tr.	0.0013	0.0003	0.35	17.53	1.65	Comparative Steel
41	0.0016	2.78	1.58	0.014	0.0004	1.33	0.0015	0.0003	tr.	tr.	tr.	tr.	0.0013	0.0037	0.35	16.28	1.65	Comparative Steel
42	0.0017	2.79	1.56	0.013	0.0003	1.32	0.0060	0.0005	tr.	tr.	tr.	tr.	0.0014	0.0003	0.35	16.41	1.65	Comparative Steel
43	0.0059	2.79	1.57	0.012	0.0005	1.32	0.0010	0.0002	tr.	tr.	tr.	tr.	0.0011	0.0003	0.35	16.45	1.65	Comparative Steel

[0047] As seen from Table 1, the steel sheets satisfying the chemical composition of the invention, particularly the steel sheets decreasing Bi content are excellent in the high-frequency iron loss property irrespectively of a high Mn content.

Claims

1. A non-oriented electrical steel sheet having a chemical composition comprising C: not more than 0.005 mass%, Si: 1.5-4 mass%, Mn: 1.0-5 mass%, P: not more than 0.1 mass%, S: not more than 0.005 mass%, Al: not more than 3 mass%, N: not more than 0.005 mass%, Bi: not more than 0.0030 mass% and the remainder being Fe and inevitable impurities.

2. A non-oriented electrical steel sheet according to claim 1, which further contains one or two of Ca: 0.0005-0.005 mass% and Mg: 0.0002-0.005 mass% in addition to the above chemical composition.

3. A non-oriented electrical steel sheet according to claim 1 or 2, which further contains one or two of Sb: 0.0005-0.05 mass% and Sn: 0.0005-0.05 mass% in addition to the above chemical composition.

4. A non-oriented electrical steel sheet according to any one of claims 1 to 3, which further contains Mo: 0.0005-0.0030 mass% in addition to the above chemical composition.

5. A non-oriented electrical steel sheet according to any one of claims 1 to 4, which contains Ti: not more than 0.002 mass%.

FIG. 1

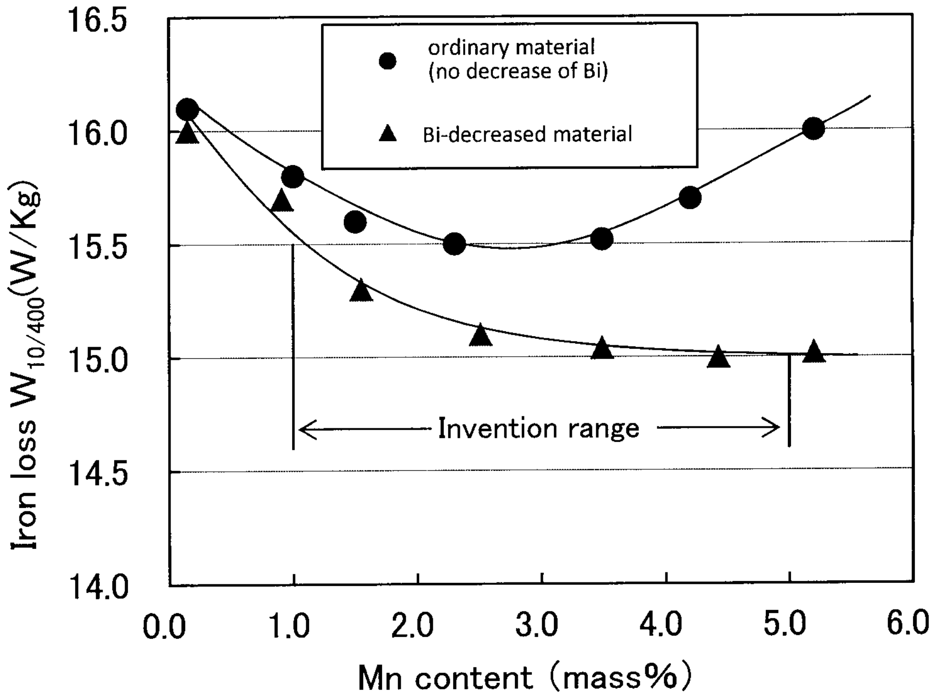
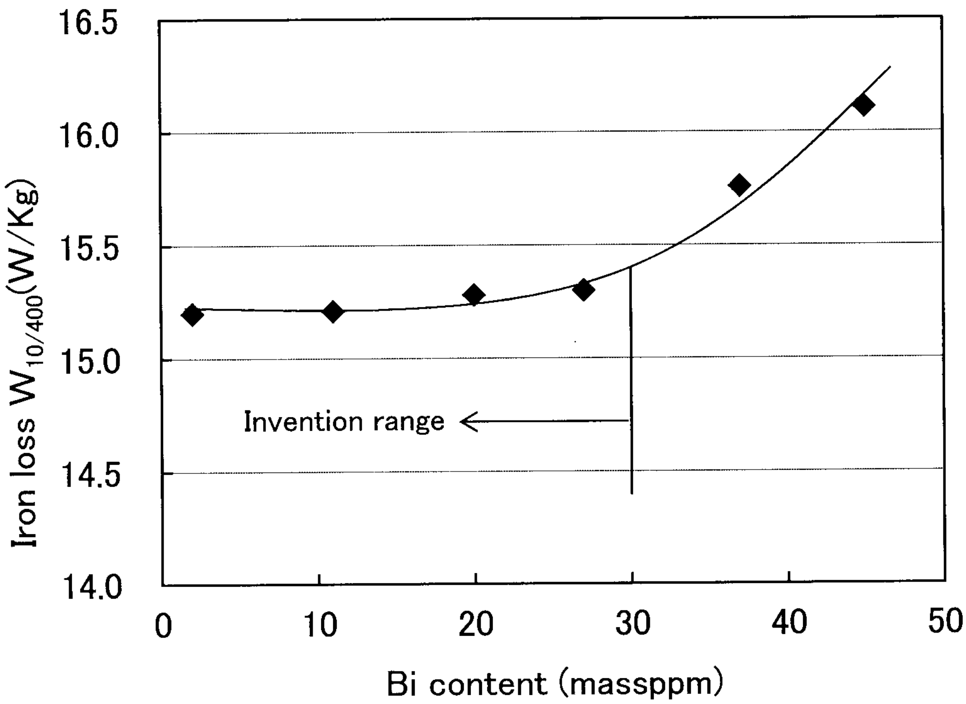

16.5
16.0
15.5
15.0
14.5
14.0
Iron loss $W_{10/400}$(W/Kg)
ordinary material
(no decrease of Bi)
Bi-decreased material
Invention range
0.0
1.0
2.0
3.0
4.0
5.0
6.0
Mn content (mass%)

FIG. 2


16.5
16.0
15.5
15.0
14.5
14.0
Iron loss $W_{10/400}$(W/Kg)
Invention range
0
10
20
30
40
50
Bi content (massppm)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2014/056430

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C22C38/06*(2006.01)i, *C22C38/60*(2006.01)i, *H01F1/16*(2006.01)i

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)
C22C38/00-38/60, H01F1/16

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2014
Kokai Jitsuyo Shinan Koho	1971-2014	Toroku Jitsuyo Shinan Koho	1994-2014

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	JP 2002-47542 A (Sumitomo Metal Industries, Ltd.), 15 February 2002 (15.02.2002), examples (Family: none)	1-5 1-5
X Y	JP 2003-55746 A (Sumitomo Metal Industries, Ltd.), 26 February 2003 (26.02.2003), examples (Family: none)	1-5 1-5
X Y	JP 2008-156737 A (JFE Steel Corp.), 10 July 2008 (10.07.2008), examples (Family: none)	1-5 1-5

☒ Further documents are listed in the continuation of Box C.   ☐ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 May, 2014 (19.05.14)	27 May, 2014 (27.05.14)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2014/056430

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	WO 2010/140509 A1 (Nippon Steel Corp.), 09 December 2010 (09.12.2010), claims & WO 2010/140509 A1 & US 2012/0014828 A1 & EP 2439302 A1 & RU 2011152605 A & TW 201105807 A & CN 102459675 A & KR 10-2012-0014576 A	1-5
Y	WO 2011/155183 A1 (JFE Steel Corp.), 15 December 2011 (15.12.2011), paragraph [0032] & JP 2011-256437 A & TW 201207121 A	4,5
A	CN 102634742 A (SHOUGANG CORP.), 15 August 2012 (15.08.2012), table 1 (Family: none)	1-5

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- JP 2002030397 A **[0006]**