



(11) **EP 2 316 980 A1**

(12) **EUROPEAN PATENT APPLICATION**  
published in accordance with Art. 153(4) EPC

(43) Date of publication:  
**04.05.2011 Bulletin 2011/18**

(21) Application number: **09800350.2**

(22) Date of filing: **15.07.2009**

(51) Int Cl.:  
**C22C 38/00** (2006.01) **C22C 19/03** (2006.01)  
**C22C 38/06** (2006.01) **C23C 30/00** (2006.01)  
**H01F 1/16** (2006.01) **H01F 1/18** (2006.01)

(86) International application number:  
**PCT/JP2009/062822**

(87) International publication number:  
**WO 2010/010836 (28.01.2010 Gazette 2010/04)**

(84) Designated Contracting States:  
**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR  
HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL  
PT RO SE SI SK SM TR**  
Designated Extension States:  
**AL BA RS**

(30) Priority: **22.07.2008 JP 2008188997**

(71) Applicant: **Nippon Steel Corporation**  
**Chiyoda-ku**  
**Tokyo**  
**100-8071 (JP)**

(72) Inventors:  
• **ARITA, Yoshihiro**  
**Tokyo 100-8071 (JP)**

- **USHIGAMI, Yoshiyuki**  
**Tokyo 100-8071 (JP)**
- **HIRANO, Shigeru**  
**Tokyo 100-8071 (JP)**
- **FUJII, Hiroyasu**  
**Tokyo 100-8071 (JP)**
- **YAMAGUCHI, Toshinao**  
**Fukuoka-shi**  
**Fukuoka 811-0295 (JP)**
- **KOIKE, Isao**  
**Fukuoka-shi**  
**Fukuoka 811-0295 (JP)**

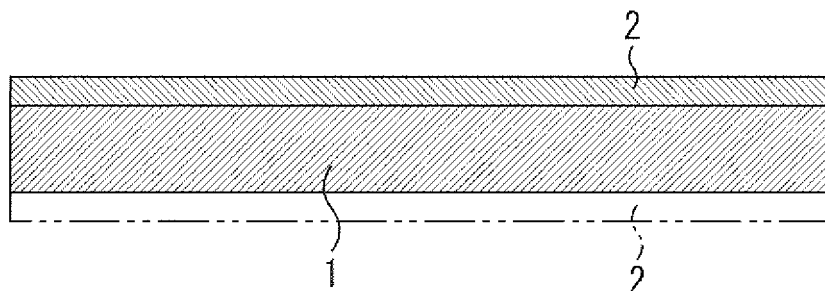
(74) Representative: **Vossius & Partner**  
**Siebertstrasse 4**  
**81675 München (DE)**

(54) **NON-ORIENTED ELECTROMAGNETIC STEEL PLATE AND METHOD FOR MANUFACTURING THE SAME**

(57) A non-oriented electrical steel sheet is provided with a base material and an Fe-Ni alloy film formed on at least one surface of the base material. The Fe-Ni alloy

film contains, by mass%, Fe: 10% to 40% and Ni: 60% to 90%, and has a thickness of 0.1  $\mu\text{m}$  or more are provided.

**FIG. 5**



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## Description

### TECHNICAL FIELD

5 **[0001]** The present invention relates to a non-oriented electrical steel sheet suitable for an iron core material of an electrical apparatus and a method of manufacturing the same.

### BACKGROUND ART

10 **[0002]** In recent years, a low-loss electrical steel sheet has been used for a small-sized general-purpose motor and a compressor motor. In the electrical steel sheet as above, by mainly improving purity and coarsening crystal grains, a magnetizing property in a low magnetic field of about 1.0 T or less has been improved.

**[0003]** Further, in recent years, higher performance properties have been required for a non-oriented electrical steel sheet to be used as an iron core material of a rotor due to a worldwide increase in achievement of energy saving of an electrical apparatus.

15 **[0004]** However, it is difficult to further improve purity of an electrical steel sheet industrially. Further, a reduction in a core loss by coarsening crystal grains is saturated when a crystal grain diameter is 150  $\mu\text{m}$  or so, but a crystal grain diameter of a conventional electrical steel sheet has already reached 150  $\mu\text{m}$  or so. Thus, even though crystal grains are further coarsened, it is difficult to further reduce a core loss.

20 **[0005]** As described above, it has been difficult to further improve a magnetic property in a low magnetic field in a conventional art.

### CITATION LIST

#### 25 PATENT LITERATURE

##### **[0006]**

Patent Document 1: Japanese Laid-open Patent Publication No. 07-070719

30 Patent Document 2: Japanese Laid-open Patent Publication No. 08-165520

Patent Document 3: Japanese Laid-open Patent Publication No. 08-283853

### SUMMARY OF THE INVENTION

#### 35 TECHNICAL PROBLEM

**[0007]** The present invention has an object to provide a non-oriented electrical steel sheet in which a magnetic property in a low magnetic field is allowed to be further improved and a method of manufacturing the same.

#### 40 SOLUTION TO PROBLEM

**[0008]** The present invention has been made in order to solve problems described above, and the gist thereof is as follows.

##### **[0009]**

45 (1) A non-oriented electrical steel sheet includes: a base material; and an Fe-Ni alloy film formed on at least one surface of the base material, containing, by mass%, Fe: 10% to 40% and Ni: 60% to 90%, and having a thickness of 0.1  $\mu\text{m}$  or more.

(2) The non-oriented electrical steel sheet described in (1), wherein the thickness of the Fe-Ni alloy film is equal to or less than 0.6  $\mu\text{m}$ .

50 (3) The non-oriented electrical steel sheet described in (1) or (2), in which the base material contains, by mass%: C: 0.05% or less; Si: not less than 0.1% nor more than 7.0%; and Al: not less than 0.01% nor more than 7.0%, and a balance of the base material is composed of Fe and inevitable impurities.

55 (4) The non-oriented electrical steel sheet described in any one of (1) to (3), further includes an insulating film formed on a surface of the base material.

##### **[0010]**

(5) A method of manufacturing a non-oriented electrical steel sheet includes: forming, on at least one surface of a base material, an Fe-Ni alloy film that contains, by mass%, Fe: 10% to 40% and Ni: 60% to 90% to have a thickness of 0.1  $\mu\text{m}$  or more.

(6) The method of manufacturing the non-oriented electrical steel sheet described in (5), in which the thickness of the Fe-Ni alloy film is equal to or less than 0.6  $\mu\text{m}$ .

(7) The method of manufacturing the non-oriented electrical steel sheet described in (5) or (6), in which the base material contains, by mass%: C: 0.05% or less; Si: not less than 0.1% nor more than 7.0%; and Al: not less than 0.01% nor more than 7.0%, and a balance of the base material is composed of Fe and inevitable impurities.

(8) The method of manufacturing the non-oriented electrical steel sheet described in any one of (5) to (7), further includes forming an insulating film on a surface of the base material, before the forming the Fe-Ni alloy film.

(9) The method of manufacturing the non-oriented electrical steel sheet described in any one of (5) to (7), further includes forming an insulating film on a surface of the base material, after the forming the Fe-Ni alloy film.

#### ADVANTAGEOUS EFFECTS OF INVENTION

**[0011]** According to the present invention, by a function of an appropriate Fe-Ni alloy film, magnetic domains on a surface of a base material are appropriately controlled, so that a magnetic property can be improved.

#### BRIEF DESCRIPTION OF DRAWINGS

##### **[0012]**

[Fig. 1] Fig. 1 is a view showing magnetic properties in case of a low magnetic field;

[Fig. 2] Fig. 2 is a view showing a relationship between a frequency and a core loss improvement rate;

[Fig. 3] Fig. 3 is a view showing a relationship between a Ni content and a relative permeability;

[Fig. 4] Fig. 4 is a view showing relationships between a thickness of an Fe-Ni alloy film and the relative permeability;

[Fig. 5] Fig. 5 is a cross-sectional view showing a structure of a non-oriented electrical steel sheet according to an embodiment of the present invention;

[Fig. 6] Fig. 6 is a cross-sectional view showing a structure of a non-oriented electrical steel sheet according to another embodiment of the present invention; and

[Fig. 7] Fig. 7 is a cross-sectional view showing a structure of a non-oriented electrical steel sheet according to still another embodiment of the present invention.

#### DESCRIPTION OF EMBODIMENTS

**[0013]** The present inventors found that, when an Fe-Ni alloy film is coated on a base material of a non-oriented electrical steel sheet, magnetic domains in the vicinity of a surface of the non-oriented electrical steel sheet are aligned in a direction parallel to the surface thereof, though details will be described later. Further, as a result, the present inventors also found that a magnetizing property in a low magnetic field (that is, for example, 0.8 T or so) is improved. The improvement in the magnetizing property in the low magnetic field can contribute to achievement of energy saving of an electrical apparatus, for example. Note that in the following explanation, a unit of a content of an element is mass% or mass ppm.

**[0014]** The present inventors formed an Fe-78%Ni alloy film on one surface of a non-oriented electrical steel sheet (base material) by a sputtering method. That is, one surface of a non-oriented electrical steel sheet was coated with an Fe-78 Ni alloy film. As the non-oriented electrical steel sheet, one containing C: 0.002%, Si: 3.0%, and Al: 0.5%, a balance of which being composed of Fe and inevitable impurities, and having a thickness of 0.35 mm was used. Further, a thickness of the Fe-78%Ni alloy film was set to 0.4  $\mu\text{m}$ . Then, a DC magnetizing property was measured. When measuring the DC magnetizing property, a relationship between a maximum magnetic flux density  $B_m$  (0.4 T to 1.6 T) and a relative permeability  $\mu_s$  was obtained. At this time, the relative permeability  $\mu_s$  was measured in a rolling direction. For comparison, similar measurement was also conducted in a non-oriented electrical steel sheet having no Fe-78%Ni alloy film formed thereon. Results thereof are shown in Fig. 1.

**[0015]** As shown in Fig. 1, in the non-oriented electrical steel sheet having the Fe-78%Ni alloy film formed thereon, the relative permeability  $\mu_s$  in a low magnetic field was increased as compared with the one having no Fe-78%Ni alloy film formed thereon. That is, a magnetic property in a low magnetic field was improved. Particularly, in the case of the maximum magnetic flux density  $B_m$  being 0.8 T or so, the relative permeability  $\mu_s$  was maximum. Incidentally, the relative permeability in the case of the maximum magnetic flux density  $B_m$  being 0.8 T is a relative permeability to be obtained from a DC magnetization curve in which the maximum magnetic flux density is 0.8 T.

**[0016]** The present inventors obtained a relationship between a frequency (20 Hz to 400 Hz) and a core loss  $W_1$  in

the case of the maximum magnetic flux density  $B_m$  being 1.5 T in the non-oriented electrical steel sheet having the Fe-78%Ni alloy film formed thereon. Further, in the non-oriented electrical steel sheet having no Fe-78 Ni alloy film formed thereon, they obtained a relationship between a frequency (20 Hz to 400 Hz) and a core loss  $W_2$  in the case of the maximum magnetic flux density  $B_m$  being 1.5 T. Then, these relationships were compared.

[0017] As a result, at frequencies of 400 Hz or less, the core loss  $W_1$  was lower than the core loss  $W_2$ . Fig. 2 shows a relationship between a frequency and a core loss improvement rate. The core loss improvement rate is expressed by the following expression.

core loss improvement rate (%) =  $100 \times (1 - W_1/W_2)$

[0018] As shown in Fig. 2, at frequencies of 400 Hz or less, the core loss improvement rate was 15% or more.

[0019] When the results shown in Fig. 1 and a result shown in Fig. 2 are considered, it can be said that the formation of the Fe-78%Ni alloy film leads to the improvement of the relative permeability  $\mu_s$  and the reduction of the core loss (a hysteresis loss). The core loss at the maximum magnetic flux density of 1.5 T and at a frequency of 50 Hz is described as  $W_{15/50}$ .

[0020] The present inventors formed Fe-Ni alloy films having various compositions (Ni: 0% to 100%) on one surface of a non-oriented electrical steel sheet by an electroplating method in order to find the composition of the Fe-Ni alloy film suitable for improving a magnetic property. That is, one surface of a non-oriented electrical steel sheet was coated with Fe-Ni alloy films having different compositions. As the non-oriented electrical steel sheet, one containing C: 0.003%, Si: 2.1%, and Al: 0.3%, a balance of which being composed of Fe and inevitable impurities, and having a thickness of 0.35 mm was used. Further, thicknesses of the Fe-Ni alloy films were set to 0.3  $\mu\text{m}$  in any of the compositions. Then, a DC magnetizing property was measured. When measuring the DC magnetizing property, the maximum magnetic flux density  $B_m$  was set to 0.8 T, and a relationship between a Ni content and the relative permeability  $\mu_s$  was obtained. A result thereof is shown in Fig. 3.

[0021] As shown in Fig. 3, in the case of the Ni content being 78.5% or so, the relative permeability  $\mu_s$  was maximum. Generally, the composition of Fe-78.5%Ni is a permalloy composition having a high magnetic permeability. On the other hand, in the case of the Ni content being less than 60%, in the case of it being less than 50% in particular, the relative permeability  $\mu_s$  was low. Further, the relative permeability  $\mu_s$  was low also in the case when the Ni content exceeded 90%. It is possible to consider that such a tendency occurs because the composition in which the Ni content is less than 60% or the composition in which it exceeds 90% has a large difference in the permalloy composition.

[0022] The present inventors formed Fe-Ni alloy films having various thicknesses (0.05  $\mu\text{m}$  to 0.8  $\mu\text{m}$ ) on one surface of a non-oriented electrical steel sheet by an immersion plating method in order to find the thickness of the Fe-Ni alloy film suitable for improving a magnetic property. That is, one surface of a non-oriented electrical steel sheet was coated with Fe-Ni alloy films having different thicknesses. As the non-oriented electrical steel sheet, one containing C: 0.003%, Si: 2.4%, and Al: 0.5%, a balance of which being composed of Fe and inevitable impurities, and having a thickness of 0.35 mm was used. Further, the Ni contents of the Fe-Ni alloy films were set to 78% in any of the thicknesses. Then, a DC magnetizing property was measured. When measuring the DC magnetizing property, the maximum magnetic flux density  $B_m$  was set to 0.8 T, and a relationship between the thickness (a coating thickness) of the Fe-Ni alloy film and the relative permeability  $\mu_s$  was obtained. Further, similar measurement was also conducted in one having the Fe-Ni alloy films formed on both surfaces of the non-oriented electrical steel sheet. Results thereof are shown in Fig. 4.

[0023] As shown in Fig. 4, when the thickness of the Fe-Ni alloy film was less than 0.1  $\mu\text{m}$ , the relative permeability  $\mu_s$  was extremely low. Further, when the thickness of the Fe-Ni alloy film exceeded 0.6  $\mu\text{m}$ , an effect of improving the relative permeability  $\mu_s$  was saturated.

[0024] The reason why the relative permeability  $\mu_s$  is extremely low when the thickness of the Fe-Ni alloy film is less than 0.1  $\mu\text{m}$  is that magnetic domains on a surface of the non-oriented electrical steel sheet are not easily aligned despite forming the Fe-Ni alloy film. Further, the reason why the effect of improving the relative permeability  $\mu_s$  is saturated is that as long as the magnetic domains on the surface of the non-oriented electrical steel sheet are sufficiently aligned, even though the Fe-Ni alloy film having the thickness of the above or more is formed, the magnetic domains are not easily aligned any more.

[0025] Further, as shown in Fig. 4, the relative permeability  $\mu_s$  in the case when the Fe-Ni alloy film was formed on one surface and the relative permeability  $\mu_s$  in the case when the Fe-Ni alloy film was formed on both surfaces were equal to each other.

[0026] This is because when excitation, a magnetic flux concentrates in a region to be most easily magnetized in a thickness direction of the non-oriented electrical steel sheet. That is, the reason is that although the Fe-Ni alloy film is formed on a single region, (one surface) in the thickness direction, or the Fe-Ni alloy films are formed on two regions (both surfaces) in the thickness direction, it is in a single region that the magnetic flux concentrates most.

[0027] The present inventors learned from these results of experiments that by forming the Fe-Ni alloy film on a surface of the non-oriented electrical steel sheet, the relative permeability and the core loss are dramatically improved. Further, the present inventors also learned that it is necessary that the Ni content of the Fe-Ni alloy film is 60% to 90% and the thickness of the Fe-Ni alloy film is 0.1  $\mu\text{m}$  or more for improving the relative permeability and the core loss. Further, the

present inventors also learned that when the thickness of the Fe-Ni alloy film exceeds 0.6  $\mu\text{m}$ , the effect of improving the relative permeability and the core loss is saturated, and even though the Fe-Ni alloy film is formed on one surface or it is formed on both surfaces, the effect of improving the relative permeability and the core loss is equal to each other in both the cases.

**[0028]** Next, the details of the present invention that has been made based on these new findings will be explained. First, there will be explained a composition of a non-oriented electrical steel sheet itself (base material), on a surface of which an Fe-Ni alloy film is to be formed.

**[0029]** When a C content exceeds 0.05%, a core loss is easily increased remarkably. Thus, the C content is preferably 0.05% or less.

**[0030]** Si is an element effective to increase electrical resistance, and when a Si content is less than 0.1%, it becomes difficult to obtain sufficient resistivity. On the other hand, when the Si content ratio of exceeds 7%, cold-rolling performance is easily lowered remarkably. Thus, the Si content is preferably not less than 0.1% nor more than 7%.

**[0031]** Al is an element effective to increase electrical resistance similarly to Si. Further, Al is an element also contributing to deoxidation, and when an Al content is less than 0.01%, it is difficult to perform sufficient deoxidation. On the other hand, when the Al content exceeds 7%, castability is lowered, and productivity is easily lowered. Thus, the Al content is preferably not less than 0.01% nor more than 7%.

**[0032]** Further, other components of the non-oriented electrical steel sheet (base material) are not limited in particular, but contents of Mn, Ti, N, S, Sn, Cu, and Ni preferably fall within the following ranges.

**[0033]** Mn generates MnS, and has an effect of rendering S being an impurity harmless. Thus, Mn is preferably contained 0.1% or more. However, even though Mn is contained more than 1.0%, the effect of rendering S harmless becomes saturated.

**[0034]** Ti generates nitride and/or carbide to deteriorate a magnetizing property and a core loss. Thus, the Ti content is preferably 30 ppm or less, and more preferably 15 ppm or less.

**[0035]** N generates AlN and/or TiN to deteriorate a magnetizing property. Thus, the N content is preferably 0.0030% or less.

**[0036]** S generates MnS to deteriorate a magnetizing property and a core loss. Thus, the S content is preferably 30 ppm or less.

**[0037]** Sn, Cu, and Ni have a function of inhibiting nitridation and oxidation of a surface of a non-oriented electrical steel sheet during annealing, which is strain relief annealing in particular, and have a function of improving an excitation property by an improvement in aggregate structure. Thus, Sn, Cu, and Ni are preferably contained 0.01% or more in total. These effects are equal among Sn, Cu, and Ni, so that at least one type of them is only sufficient to be contained. However, even though Sn, Cu, and Ni are contained more than 0.50% in total, the function of inhibiting nitridation and oxidation by atmosphere gas during annealing and the function of improving aggregate structure is saturated.

**[0038]** Next, the Fe-Ni alloy film will be explained.

**[0039]** The Fe-Ni alloy film is preferably composed of Fe: 10% to 40% and Ni: 90% to 60%, and more preferably composed of Fe: 15% to 30% and Ni: 85% to 70%. This is to obtain a good magnetic property in a low magnetic field. Incidentally, other metallic elements such as Mo may also be contained in the Fe-Ni alloy film. In the above case, the Fe-Ni alloy film preferably contains Fe: 10% to 40% and Ni: 90 to 60%, and more preferably contains Fe: 15% to 30% and Ni: 85% to 70%.

**[0040]** A method of forming the Fe-Ni alloy film on a surface of the non-oriented electrical steel sheet (base material) is not limited in particular. It is possible to form the Fe-Ni alloy film on a surface of the non-oriented electrical steel sheet by, for example, a dry coating method such as a PVD (physical vapor deposition) method and a CVD (chemical vapor deposition) method, and a wet coating method such as a plating method.

**[0041]** The thickness of the Fe-Ni alloy films is set to 0.1  $\mu\text{m}$  or more. This is because the sufficient effects cannot be obtained when the thickness is less than 0.1  $\mu\text{m}$  as described above. On the other hand, when the thickness of the Fe-Ni alloy film exceeds 0.6  $\mu\text{m}$ , the effect of improving the relative permeability and the core loss is saturated, so that the thickness of the Fe-Ni alloy film is sufficiently 0.6  $\mu\text{m}$  or less. However, the thickness may also exceed 0.6  $\mu\text{m}$  for a reason such as operation stability.

**[0042]** Further, as described above, the Fe-Ni alloy film is sufficiently formed on one surface of the non-oriented electrical steel sheet (base material), but it may also be formed on both surfaces of the non-oriented electrical steel sheet (base material).

**[0043]** Next, there will be explained a magnetic property of the non-oriented electrical steel sheet having the Fe-Ni alloy film formed on at least one surface thereof.

**[0044]** As for the DC magnetizing property of the non-oriented electrical steel sheet having the Fe-Ni alloy film formed on one surface thereof, in the above-described experiments, the relative permeability  $\mu_s$  in the rolling direction exhibited a maximum value at the maximum magnetic flux density  $B_m$  of 0.8 T or so, and the value was 10000 or more. Thus, it is possible to consider that as long as minimum various conditions as above are satisfied, the relative permeability  $\mu_s$  of 10000 or more can be obtained at the maximum magnetic flux density  $B_m$  of 0.8 T.

**[0045]** Further, in the above-described experiments, at frequencies of 400 Hz or less, by forming the Fe-Ni alloy film, the core loss was improved by 15% or more. Thus, it is possible to consider that as long as the above-described minimum various conditions are satisfied, in any direction, by forming the Fe-Ni alloy film, the core loss is improved by 10% or more.

**[0046]** Incidentally, a method of manufacturing the non-oriented electrical steel sheet as the base material, namely the non-oriented electrical steel sheet before the Fe-Ni alloy film is formed thereon, is not limited in particular, and the non-oriented electrical steel sheet can be manufactured according to a conventional method. For example, annealing after hot rolling may also be performed as needed. Further, a thickness of the non-oriented electrical steel sheet after cold rolling may also be set to 0.10 mm to 0.80 mm depending on a required property. Further, a finish annealing temperature may also be adjusted within a range of 700°C to 1100°C depending on a required property. Further, strain relief annealing may also be performed after a punching-out process of a motor core or the like.

**[0047]** Further, when manufacturing the non-oriented electrical steel sheet as the base material, an insulating film is formed on a surface of the non-oriented electrical steel sheet after finish annealing, and the Fe-Ni alloy film may also be formed after the above insulating film is formed. Further, the Fe-Ni alloy film may also be formed before the above insulating film is formed.

**[0048]** The non-oriented electrical steel sheet according to an embodiment of the present invention is provided with a structure shown in Fig. 5, for example. That is, on one surface or both surfaces of a base material 1, an Fe-Ni alloy film 2 is formed. As shown in Fig. 6, an insulating film 3 may also be formed between the base material 1 and the Fe-Ni alloy film 2, and as shown in Fig. 7, the insulating film 3 may also be formed on the Fe-Ni alloy film 2.

**[0049]** Next, there will be explained experiments for confirming the effects of the present invention conducted by the present inventors.

#### <Experiment 1>

**[0050]** Each of Fe-Ni alloy films having compositions shown in Table 1 was formed on one surface or both surfaces of a non-oriented electrical steel sheet (base materials), which was after finish annealing and before an insulating film was formed thereof, by an electroplating method. That is, one surface or both surfaces of a non-oriented electrical steel sheet was/were coated with Fe-Ni alloy film(s). As the non-oriented electrical steel sheet, one containing C: 0.002%, Si: 3.2%, and Al: 1.0%, a balance of which being composed of Fe and inevitable impurities, and having a thickness of 0.35 mm was used. Further, thickness of the Fe-Ni alloy film was set to 0.5  $\mu\text{m}$  per one surface. Next, an insulating film was formed on an entire surface of the non-oriented electrical steel sheet. Then, the relative permeability  $\mu_s$  in the rolling direction at the maximum magnetic flux density  $B_m$  of 0.8 T was measured. A result thereof is shown in Table 1.

**[0051]**

[Table 1]

| Sample number | Fe (mass%) | Ni (mass%) | Coated surface | Relative permeability | Note                |
|---------------|------------|------------|----------------|-----------------------|---------------------|
| 1-1           | 48         | 52         | one surface    | 8400                  | Comparative example |
|               |            |            | both surfaces  | 8450                  | Comparative example |
| 1-2           | 39         | 61         | one surface    | 10100                 | invention example   |
|               |            |            | both surfaces  | 10200                 | Invention example   |
| 1-3           | 19         | 81         | one surface    | 12000                 | Invention example   |
|               |            |            | both surfaces  | 11800                 | Invention example   |
| 1-4           | 11         | 89         | one surface    | 10200                 | Invention example   |
|               |            |            | both surfaces  | 10100                 | Invention example   |
| 1-5           | 7          | 93         | one surface    | 8800                  | Comparative example |
|               |            |            | both surfaces  | 8900                  | Comparative example |

**[0052]** As shown in Table 1, in samples in which the Ni content of the Fe-Ni alloy film were 60% to 90%, the high relative permeability  $\mu_s$  of 10000 or more was obtained. On the other hand, in a sample in which the Ni content was less than 60% and a sample in which the Ni content exceeded 90%, the relative permeability  $\mu_s$  was lowered to less than 10000. These tendencies were common between the samples in which the Fe-Ni alloy film was formed on only one surface and the samples in which the Fe-Ni alloy films were formed on both surfaces.

## &lt;Experiment 2&gt;

**[0053]** Each of Fe-78%Ni alloy films having thicknesses shown in Table 2 was formed on one surface of a non-oriented electrical steel sheet (base materials), which was after finish annealing and before an insulating film was formed thereon, by a PVD method. That is, Fe-78%Ni alloy film was coated on one surface of a non-oriented electrical steel sheet. As the non-oriented electrical steel sheet, one containing C: 0.001%, Si: 4.5%, and Al: 3.5%, a balance of which being composed of Fe and inevitable impurities, and having a thickness of 0.30 mm was used. Next, an insulating film was formed on an entire surface of the non-oriented electrical steel sheet. Then, the relative permeability  $\mu_s$  in the rolling direction at the maximum magnetic flux density  $B_m$  of 0.8 T was measured. A result thereof is shown in Table 2.

**[0054]**

[Table 2]

| Sample number  | Film thickness ( $\mu\text{m}$ ) | Relative permeability | Evaluation |
|--|----------------------------------|-----------------------|------------|
| 2-1  | 0.00                             | 5000                  | ×          |
| 2-2  | 0.05                             | 8000                  | ×          |
| 2-3  | 0.1                              | 10000                 | ◎          |
| 2-4  | 0.2                              | 10300                 | ◎          |
| 2-5  | 0.4                              | 10500                 | ◎          |
| 2-6  | 0.6                              | 10800                 | ◎          |
| 2-7  | 0.8                              | 11000                 | ○          |
| 2-8  | 0.9                              | 11000                 | ○          |
| 2-9  | 1.0                              | 11000                 | ○          |
| Evaluation: ◎ particularly effective (the film thickness of 0.1 to 0.6 $\mu\text{m}$ )<br>○ one that is effective but saturated (the film thickness of over 0.6 $\mu\text{m}$ )<br>× comparative example (the film thickness of less than 0.1. $\mu\text{m}$ ) |                                  |                       |            |

**[0055]** As shown in Table 2, in samples in which the thickness of the Fe-Ni alloy film was 0.1  $\mu\text{m}$  or more, the high relative permeability  $\mu_s$  of 10000 or more was obtained. Further, in samples in which the thickness of the Fe-Ni alloy film was less than 0.1  $\mu\text{m}$ , the relative permeability  $\mu_s$  was lowered to less than 10000. Further, when the thickness of the Fe-Ni alloy film exceeded 0.6  $\mu\text{m}$ , the effects was saturated.

## &lt;Experiment 3&gt;

**[0056]** Each of Fe-Ni alloy films having compositions shown in Table 3 was formed on one surface of a non-oriented electrical steel sheet (base material), which was after finish annealing and before an insulating film was formed thereon, by an immersion plating method. That is, an Fe-Ni alloy films was coated on one surface of a non-oriented electrical steel sheet. As the non-oriented electrical steel sheet, one containing C: 0.01%, Si: 2.5%, and Al : 4.5%, a balance of which being composed of Fe and inevitable impurities, and having a thickness of 0.50 mm was used. Further, thickness of the Fe-Ni alloy film was set to 0.4  $\mu\text{m}$ . Next, an insulating film was formed on an entire surface of the non-oriented electrical steel sheet. Then, the relative permeability  $\mu_s$  in the rolling direction at the maximum magnetic flux density  $B_m$  of 0.8 T was measured. Further, a core loss W15/50, (which is a core loss at the maximum magnetic flux density  $B_m$  of 1.5 T and at a frequency of 50 Hz), was also measured. Results thereof are shown in Table 3.

**[0057]**

[Table 3]

| Sample number | Fe (mass%) | Ni (mass%) | Relative permeability | W15/50 (W/kg) | Core loss improvement rate (%) | Evaluation |
|---------------|------------|------------|-----------------------|---------------|--------------------------------|------------|
| 3-1           | -          | -          | 7000                  | 2.35          | base                           | ×          |
| 3-2           | 35         | 65         | 10100                 | 2.22          | 5.5                            | ○          |

(continued)

| Sample number  | Fe (mass%) | Ni (mass%) | Relative permeability | W15/50 (W/kg) | Core loss improvement rate (%) | Evaluation |
|--|------------|------------|-----------------------|---------------|--------------------------------|------------|
| 3-3  | 30         | 70         | 11800                 | 2.02          | 14.0                           | ⊙          |
| 3-4  | 25         | 75         | 12300                 | 1.98          | 15.7                           | ⊙          |
| 3-5  | 20         | 80         | 12700                 | 1.92          | 18.3                           | ⊙          |
| 3-6  | 15         | 85         | 12100                 | 2.05          | 12.8                           | ⊙          |
| 3-7  | 10         | 90         | 10200                 | 2.19          | 6.8                            | O          |
| Evaluation: ⊙ particularly effective (the core loss improvement rate of over 10%)<br>O effective (the relative permeability of 10000 or more, and the core loss improvement rate of less than 10%)<br>× comparative example (the relative permeability of less than 10000) |            |            |                       |               |                                |            |

**[0058]** As shown in Table 3, the relative permeability  $\mu_s$  was 10000 or more in all samples in which the Fe-Ni alloy film was formed. Further, in the samples in which the Ni content of the Fe-Ni alloy film was 70% to 85%, the core loss improvement rate was increased to 10% or more.

#### INDUSTRIAL APPLICABILITY

**[0059]** The present invention can be utilized for a non-oriented electrical steel sheet to be used for a motor or the like.

#### Claims

1. A non-oriented electrical steel sheet comprising:

a base material; and  
 an Fe-Ni alloy film formed on at least one surface of said base material, containing, by mass%, Fe: 10% to 40% and Ni: 60% to 90%, and having a thickness of 0.1  $\mu\text{m}$  or more.

2. The non-oriented electrical steel sheet according to claim 1, wherein the thickness of said Fe-Ni alloy film is equal to or less than 0.6  $\mu\text{m}$ .

3. The non-oriented electrical steel sheet according to claim 1, wherein said base material contains, by mass%:

C: 0.05% or less;  
 Si: not less than 0.1% nor more than 7.0%; and  
 Al: not less than 0.01% nor more than 7.0%, and  
 a balance of said base material is composed of Fe and inevitable impurities.

4. The non-oriented electrical steel sheet according to claim 2, wherein said base material contains, by mass%:

C: 0.05% or less;  
 Si: not less than 0.1% nor more than 7.0%; and  
 Al: not less than 0.01% nor more than 7.0%, and  
 a balance of said base material is composed of Fe and inevitable impurities.

5. The non-oriented electrical steel sheet according to claim 1, further comprising an insulating film formed on a surface of said base material.

6. The non-oriented electrical steel sheet according to claim 2, further comprising an insulating film formed on a surface of said base material.



7. The non-oriented electrical steel sheet according to claim 3, further comprising an insulating film formed on a surface of said base material .

8. The non-oriented electrical steel sheet according to claim 4, further comprising an insulating film formed on a surface of said base material.

9. A method of manufacturing a non-oriented electrical steel sheet comprising:

forming, on at least one surface of a base material, an Fe-Ni alloy film that contains, by mass%, Fe: 10% to 40% and Ni: 60% to 90% to have a thickness of 0.1  $\mu\text{m}$  or more.

10. The method of manufacturing a non-oriented electrical steel sheet according to claim 9, wherein the thickness of the Fe-Ni alloy film is equal to or less than 0.6  $\mu\text{m}$ .

11. The method of manufacturing a non-oriented electrical steel sheet according to claim 9, wherein the base material contains, by mass%:

C: 0.05% or less;

Si: not less than 0.1% nor more than 7.0%; and

Al: not less than 0.01% nor more than 7.0%, and

a balance of the base material is composed of Fe and inevitable impurities.

12. The method of manufacturing a non-oriented electrical steel sheet according to claim 10, wherein the base material contains, by mass%:

C: 0.05% or less;

Si: not less than 0.1% nor more than 7.0%; and

Al: not less than 0.01% nor more than 7.0%, and

a balance of the base material is composed of Fe and inevitable impurities.

13. The method of manufacturing a non-oriented electrical steel sheet according to claim 9, further comprising forming an insulating film on a surface of the base material, before said forming the Fe-Ni alloy film.

14. The method of manufacturing a non-oriented electrical steel sheet according to claim 9, further comprising forming an insulating film on a surface of the base material, after said forming the Fe-Ni alloy film.

15. The method of manufacturing a non-oriented electrical steel sheet according to claim 10, further comprising forming an insulating film on a surface of the base material, before said forming the Fe-Ni alloy film.

16. The method of manufacturing a non-oriented electrical steel sheet according to claim 10, further comprising forming an insulating film on a surface of the base material, after said forming the Fe-Ni alloy film.

FIG. 1

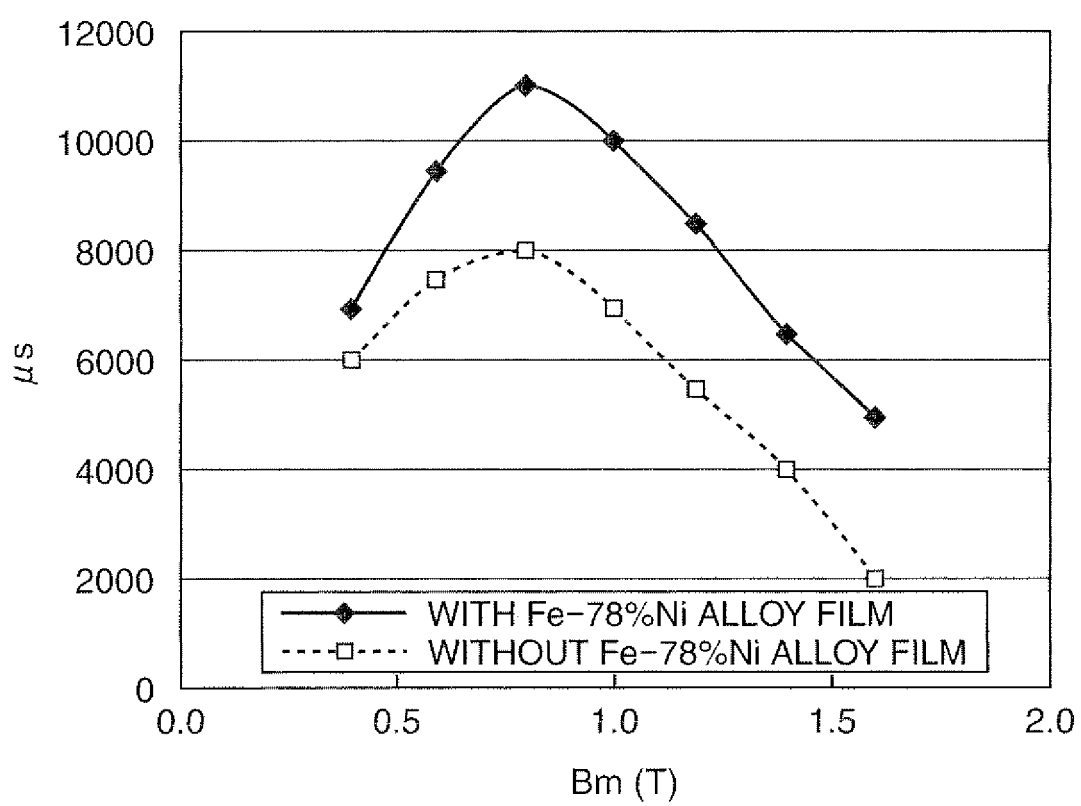


FIG. 2

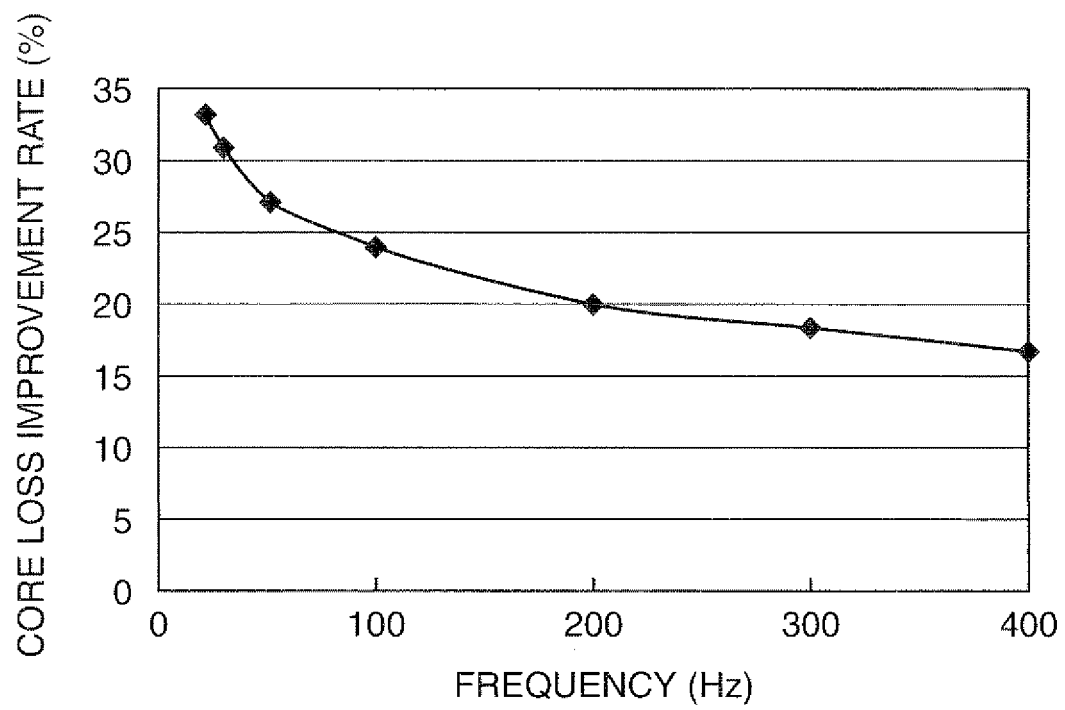


FIG. 3

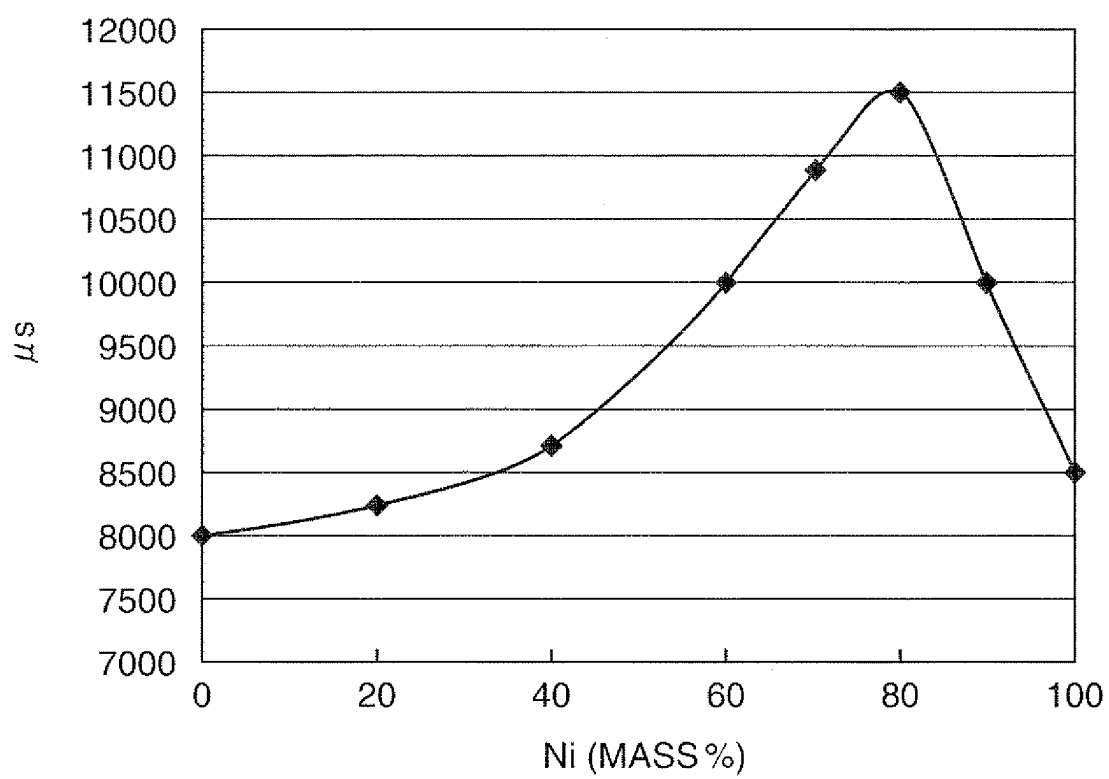


FIG. 4

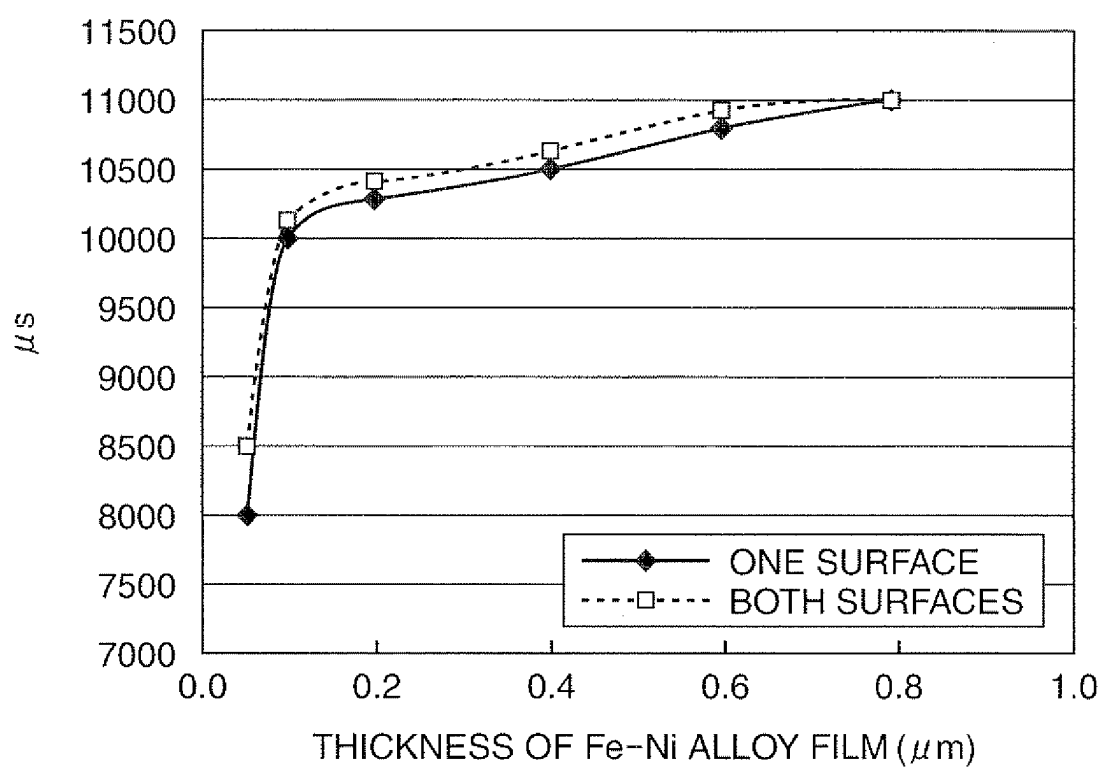


FIG. 5

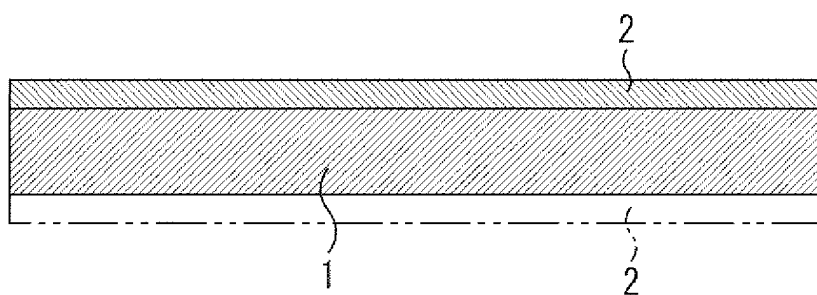


FIG. 6

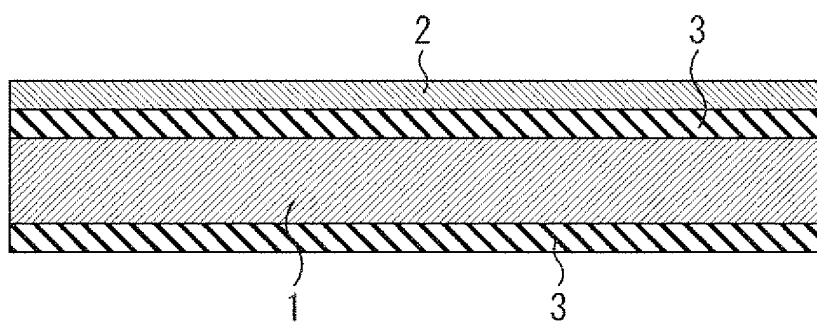
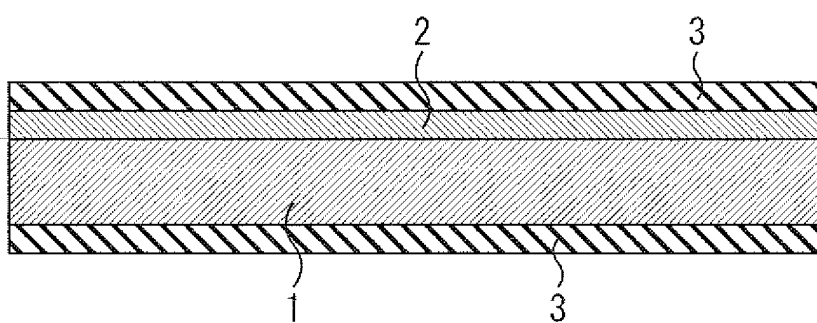


FIG. 7



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2009/062822

## A. CLASSIFICATION OF SUBJECT MATTER

C22C38/00(2006.01)i, C22C19/03(2006.01)i, C22C38/06(2006.01)i, C23C30/00(2006.01)i, H01F1/16(2006.01)i, H01F1/18(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, C22C19/03, C23C30/00, H01F1/16, H01F1/18

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 1996-2009

Kokai Jitsuyo Shinan Koho 1971-2009 Toroku Jitsuyo Shinan Koho 1994-2009

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. |
|-----------|--|-----------------------|
| A         | JP 47-25563 B1 (Nippon Steel Corp.),<br>12 July 1972 (12.07.1972),<br>(Family: none)   | 1-16                  |
| A         | JP 9-78130 A (Toyo Kohan Co., Ltd.),<br>25 March 1997 (25.03.1997),<br>& AU 7000096 A & CN 1196758 A<br>& EP 852265 A1 & KR 10-269717 B1<br>& TW 327651 B & US 6025673 A<br>& WO 97/11204 A1 | 1-16                  |
| A         | JP 4-34632 B2 (Sumitomo Metal Industries,<br>Ltd.),<br>08 June 1992 (08.06.1992),<br>(Family: none)  | 1-16                  |

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

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"&amp;" document member of the same patent family

Date of the actual completion of the international search  
13 October, 2009 (13.10.09)Date of mailing of the international search report  
20 October, 2009 (20.10.09)Name and mailing address of the ISA/  
Japanese Patent Office

Authorized officer

Facsimile No.

Telephone No.

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2009/062822

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages   | Relevant to claim No. |
|-----------|--|-----------------------|
| A         | JP 7-173641 A (Sumitomo Metal Industries, Ltd.),<br>11 July 1995 (11.07.1995),<br>(Family: none)   | 1-16                  |
| A         | JP 11-131251 A (Kawasaki Steel Corp.),<br>18 May 1999 (18.05.1999),<br>& CA 2249749 A1 & EP 913488 A2<br>& KR 10-1999-0037554 A & US 6136456 A | 1-16                  |
| E, A      | WO 2009/093492 A1 (Nippon Steel Corp.),<br>30 July 2009 (30.07.2009),<br>(Family: none)  | 1-16                  |

Form PCT/ISA/210 (continuation of second sheet) (April 2007)



**REFERENCES CITED IN THE DESCRIPTION**

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- JP 7070719 A [0006]
- JP 8165520 A [0006]
- JP 8283853 A [0006]