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(54) **NON-MAGNETIC HIGH MANGANESE STEEL SHEET WITH HIGH STRENGTH AND MANUFACTURING METHOD THEREOF**

NICHTMAGNETISCHES HOCHFESTES STAHLBLECH MIT HOHEM MANGANANTEIL UND HERSTELLUNGSVERFAHREN DAFÜR

FEUILLE D'ACIER À HAUTE TENEUR EN MANGANÈSE, NON MAGNÉTIQUE, AYANT UNE HAUTE RÉSISTANCE ET SON PROCÉDÉ DE FABRICATION

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(56) References cited:
WO-A1-2007/075006 **WO-A1-2008/078940**
WO-A1-2009/084793 **JP-A- H02 104 633**
JP-A- H04 143 218 **JP-A- H07 126 809**
KR-A- 20090 070 507 **KR-A- 20090 070 509**
KR-A- 20090 070 510 **KR-A- 20110 009 792**
KR-B1- 100 742 823 **KR-B1- 100 957 992**
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Description

[Technical Field]

[0001] The present disclosure relates to a non-magnetic high manganese steel sheet having a high degree of strength for use as a material for heavy electrical machinery such as switchboards and transformers.

[Background Art]

[0002] In general, materials for equipment such as switchboards and transformers are required to have high degrees of strength as well as good non-magnetic properties.

[0003] In the related art, stainless steel having high nickel and chromium contents and satisfying the requirements for high strength and non-magnetivity is used in such applications. However, such stainless steel is expensive and may not have sufficient strength.

[0004] Ferritic or martensitic stainless steel may be used as alternatives to satisfy the requirement for high strength. However, ferritic and martensitic stainless steels have high-quality magnetic properties that cause eddy currents and thus the loss of electrical currents. In addition, ferritic or martensitic stainless steel is very expensive.

[0005] Therefore, materials that are free of the limitations of such stainless steels while having high strength and non-magnetic properties are required. WO 2007/075006 A1 discloses a high Mn steel strip, used for steel strips in automobiles, comprising by weight%, 0.2 to 1.5% of C, 10 to 25% of Mn, 0.01 to 3.0% of Al, 0.005 to 2.0% of Si, 0.03% or less of P, 0.03% or less of S, 0.040% or less of N, and the balance of Fe and other unavoidable impurities. WO 2008/078940 A1 discloses a high manganese steel sheet including, by weight: carbon (C): 0.2 to 1.5%, manganese (Mn): 10 to 25%, aluminum (Al): 0.01 to 3.0%, phosphorus (P) 0.03% or less, sulfur (S): 0.03% or less, nitrogen (N):

0.040% or less, at least one selected from the group consisting of silicon (Si): 0.02 to 2.5%, titanium (Ti): 0.01 to 0.10% and niobium (Nb) : 0.01 to 0.10%, and the balance of Fe and other inevitable impurities. The high manganese steel sheet may be used for parts such as a front side member of an automobile since, among its characteristics, the steel sheet has an excellent impact absorbing ability.

[0006] KR 2009 0070510 A discloses a manufacturing method of high manganese steel sheet comprising a reheating step of heating a steel slab to 1050 to 1300°C to equalize, a hot rolling step of completing a steel sheet through hot-rolling at 850 to 1000°C, a step of winding the steel sheet at a temperature of 700°C or below, a step of cold-rolling the wound steel sheet at a reduction rate of 10 to 80%, and a step of continuously annealing the steel sheet at 700°C or higher. The steel sheet comprises C 0.3 to 0.9 weight%, Mn 15 to 30 weight%, Al 0.01 to 4.0 weight%, Si less than 0.1 weight%, N 0.04 weight% or less, P 0.05 weight% or less, and S 0.01 weight% or less.; The steel sheet also includes one or more selected from the group consisting of Nb 0.02~0,1 weight%, Ti 0.01~0.1 weight%, and V 0.025~0.5 weight%.

[0007] JP H07 126809 A discloses a high Mn nonmagnetic steel having a composition containing 0.40 to 0.65% C, 13.0 to 20.0% Mn, 0.1 to 1.5% Si, 0.01 to 3.0% Mo, 0.005 to 1.0% Al and 0.01 to 0.10% N, and in which the relationship between C and Mn satisfies 25%≤20C%+Mn%≤29%, and the balance Fe with inevitable impurities.

[0008] WO 2009/084793 A1 discloses a method of manufacturing a high manganese plated steel sheet including a heating step of heating a continuously cast slab at a temperature of 1050°C to 1300°C, a finish hot rolling step of performing finish hot rolling on the slab at a temperature of 850°C to 950°C, a hot rolling and coiling step of performing hot rolling and coiling on the slab at a temperature of 750°C or less, a pickling step of pickling the slab in a HCl solution having a concentration of 5% to 25% for 20 seconds or more, an annealing step of annealing the slab at a recrystallization temperature of 600°C, and a plating step of immersing the slab into a hot dip galvanizing bath so as to create a plated layer on a surface of the steel sheet.

[0009] KR 2009 0070507 A discloses a high-manganese steel sheet comprising carbon (C) 0.3 to 0.9 weight%, manganese(Mn) 15 to 30 weight%, aluminum (Al) 0.1 to 5.0 weight%, nitrogen(N) 0.04 weight% or less, sulfur(S) 0.03 weight% or less, and phosphorus(P) 0.15 weight% or less. The high-manganese steel sheet includes more than one kind of alloy elements selected from the group consisting of copper(Cu) 0.5 weight% or less, molybdenum (Mo) 1.0 weight% or less, chrome(Cr) 1.0 weight% or less, boron(B) 0.0005 to 0.04 weight% silicon(Si) 5.0 weight% or less, nickel(Ni) 2.0 weight% or less, antimony(Sb) 0.005 to 0.1 weight%, vanadium (V) 0.5 weight% or less, niobium (Nb) 0.5 weight% or less, zirconium(Zr) 0.005 to 0.10 weight%, and calcium(Ca) 0.0005 to 0.30 weight%, and inevitable impurities and the rest Fe.

[Disclosure]

[Technical Problem]

[0010] Aspects of the present disclosure may provide a non-magnetic high manganese steel sheet having high degrees of strength and formability and good non-magnetic properties, and a method of manufacturing the steel sheet.

[Technical Solution]

[0011] According to an aspect of the invention, there is provided a non-magnetic, high manganese steel sheet with high strength for heavy electrical machinery as recited in Claim 1.

[0012] According to another aspect of the invention, there is provided a method of manufacturing a non-magnetic, high manganese steel sheet with high strength for heavy electrical machinery as recited in Claim 4.

[Advantageous Effects]

[0013] According to the present disclosure, a high manganese steel sheet having high austenite stability and non-magnetic properties is provided. Aluminum (Al) is added to the steel sheet to prevent carbon from forming carbides and to thus further increase the stability of austenite. Therefore, the steel sheet has a high degree of formability as well as a high degree of strength. The steel sheet has a sufficient degree of rigidity and thus can be used to form a structural member of a large transformer.

[Description of Drawings]

[0014]

FIGS. 1A and 1B are microstructure images of Comparative Examples 1-5 and Comparative Examples 1-3, respectively.

FIG. 2 is an XRD graph in which curves A and B show phase-stability measurement results of Inventive Steel 2-1 and Comparative Steel 2-1, respectively.

FIGS. 3A and 3B are microstructure images of Inventive Steel 2-1 and Comparative Steel 2-1, respectively.

[Best Mode]

[0015] Eddy current loss occurring when a material is placed in a magnetic field is closely related to the magnetic properties of the material. More eddy current is generated in a material having better magnetic properties, and thus more eddy current loss is generated. In general, the magnetism of a material is proportional to the permeability (μ) of the material. That is, the higher the permeability, the higher the magnetism. Permeability is defined as μ=B/H where H denotes a magnetic field and B denotes an induced magnetic field. That is, if the permeability of a material is reduced, the magnetism of the material is reduced, and thus when the material is placed in a magnetic field, loss caused by eddy currents in the surface of the material may be reduced to increase energy efficiency. Therefore, if non-magnetic steel sheets are used as materials for electric equipment such as switchboards or transformers, energy loss may be reduced.

[0016] The inventors have conducted in-depth research and have invented a high manganese steel having a high degree of strength and good non-magnetic properties by adding manganese (Mn) and carbon (C) to improve the stability of austenite. According to embodiments of the present disclosure, steel sheets having good non-magnetic properties as well as high degrees of strength and elongation (formability) are provided by controlling the contents of carbon and manganese to improve the phase stability of austenite, and adding aluminum to suppress the formation of deformation-induced ε-martensite and the generation of dislocation-induced slip deformation.

[0017] The embodiments of the present disclosure will now be described in detail. First, a steel sheet will now be described in detail according to an embodiment of the present disclosure. The steel sheet of the embodiment has the following composition (hereinafter, % refers to weight%).

Carbon (C): 0.4% to 0.9%

[0018] Carbon (C) is an element for forming austenite in steel. It may be preferable that the content of carbon (C) in the steel sheet be 0.4% or greater. However, if the content of carbon (C) is greater than 0.9%, carbides may excessively precipitate to worsen the non-magnetic properties and castability of the steel sheet. Therefore, it may be preferable that the content of carbon (C) in the steel sheet be within the range of 0.4% to 0.9%.

Manganese (Mn): 10% to 25%

[0019] Manganese (Mn) is a key element for stabilizing austenite. In the embodiment of the present disclosure, the content of manganese (Mn) in the steel sheet is 10% or greater. If the content of manganese (Mn) is less than 10%, α'-martensite may be formed to worsen the non-magnetic properties of the steel sheet. On the other hand, if the content of manganese (Mn) is greater than 25%, the manufacturing costs of the steel sheet may be markedly increased, and oxidation may be markedly increased in the steel sheet to worsen the surface quality of the steel sheet when the steel sheet is heated in a hot-rolling process. Therefore, it may be preferable that the content of manganese (Mn) be within the range of 10% to 25%.

[0020] Aluminum (Al) : 1.3% to 8.0% Aluminum (Al) is an element effective in preventing the formation of carbides and controlling the fraction of twins for improving formability. In the embodiment of the present disclosure, since carbon (C) is dissolved to stabilize austenite, aluminum (Al) is used as a key element for preventing the formation of carbides and thus improving non-magnetic properties. To this end, the content of aluminum (Al) is set to be 1. 3 % or greater. However, if the content of aluminum (Al) is greater than 8.0%, the manufacturing cost of the steel sheet may be increased, and oxides may be excessively formed to worsen the quality of the steel sheet. Therefore, it may be preferable that the content of aluminum (Al) be within the range of 1.3 % to 8.0%. According to a specific embodiment of the invention, the content of aluminum (Al) is 1.3% to 8.0%. Silicon (Si): 0.01% to 2.0%

[0021] Silicon (Si) is an element having no significant influence on stacking fault energy. Silicon (Si) is generally used as a deoxidizer, and about 0.01% of silicon (Si) is included in steel in a general steel making process. Since excessive costs are incurred in removing silicon (Si), the content of silicon (Si) in the steel sheet may be about 0.01%. In addition, if the content of silicon (Si) exceeds 2.0%, manufacturing costs are increased, and oxides are excessively generated to worsen the surface quality of the steel sheet. Therefore, the content of silicon in the steel sheet is within the range of 0.01% to 2.0%.

Titanium (Ti): 0.05% to 0.2%

[0022] Titanium (Ti) is an element reacting with nitrogen in the steel sheet to precipitate nitrides and facilitate the formation of twins. Titanium (Ti) is added to the steel sheet to improve the strength and formability of the steel sheet. In addition, titanium (Ti) improves the strength of the steel sheet by forming precipitates. To this end, it may be preferable that the content of titanium (Ti) be 0.05% or greater. However, if the content of titanium (Ti) is greater than 0.2%, precipitates may be excessively formed to generate cracks in the steel sheet during a cold-rolling process and thus to worsen the formability and weldability of the steel sheet. Therefore, the content of titanium (Ti) is within the range of 0.05% to 0.2%.

Boron (B): 0.0005% to 0.005%

[0023] A low content of Boron (B) enhances the grain boundaries of a slab, and thus it may be preferable that the content of boron (B) be 0.0005% or greater. However, if the content of boron (B) is excessive, manufacturing costs may be increased, and thus the content of boron (B) is within the range of 0.0005% to 0.005%.

Sulfur (S): 0.05% or less (excluding 0%)

[0024] The content of sulfur (S) may be adjusted to be 0.05% or less for controlling the amounts of inclusions. If the content of sulfur (S) in the steel sheet is greater than 0.05%, the steel sheet may exhibit hot brittleness, and thus the upper limit of the content of sulfur (S) is set to be 0.05%.

Phosphorus (P): 0.8% or less (excluding 0%)

[0025] Phosphorus (P) easily segregates and leads to cracks during a casting process. Therefore, it may be preferable that the content of phosphorus (P) be set to be 0.8% or less. If the content of phosphorus (P) in the steel sheet is greater than 0.8%, the castability of the steel sheet may deteriorate, and thus the upper limit of the content of phosphorus (P) is 0.08%.

Nitrogen (N): 0.003% to 0.01%

[0026] Nitrogen is inevitably included in the steel sheet because of a reaction with air during a steel making process. Excessive manufacturing costs may be incurred to reduce the content of nitrogen (N) to lower than 0.003%, and if the content of nitrogen (N) exceeds 0.01%, nitrides may be formed to worsen the formability of the steel sheet. Therefore, the content of nitrogen (N) is within the range of 0.003% to 0.01%.

[0027] The steel sheet may include iron (Fe) and inevitable impurities as the remainder of constituents.

[0028] In the embodiment of the present disclosure, it may be preferable that the microstructure of the steel sheet has 1 volume% or less of carbides. In the embodiment of the present disclosure, carbon (C) may be dissolved in the steel sheet in an atomic state to stabilize austenite. That is, if carbon (C) is present in the steel sheet in the form of carbides, the stability of austenite of the steel sheet may be decreased, and the permeability of the steel sheet may be increased to worsen non-magnetic properties of the steel sheet. Therefore, it may be preferable that the steel sheet have a low content of carbides, for example, 1 volume% or less. Particularly, it may be preferable that the content of carbides in the steel sheet be 1 volume% or less even after a heat treatment. The heat treatment includes a heat treatment during a manufacturing process of the steel sheet and a heat treatment during the use of the steel sheet.

[0029] In the embodiment of the present disclosure, the steel sheet has austenite in the microstructure thereof, and although energy such as heat is applied to the steel sheet, the steel sheet may maintain the austenite component thereof and thus retain non-magnetic properties. That is, in the embodiment of the present disclosure, the steel sheet may have austenite and a low content of carbides (1 volume% or less) according to heat-treatment conditions.

[0030] In the embodiment of the present disclosure, when the content of aluminum (Al) in the steel sheet is within the range of 1.3% to 8.0%, the stacking fault energy (SFE) of the steel sheet is 30 mJ/cm^2 or greater. The term "stacking fault energy" refers to energy in an interface between partial dislocations. In the embodiment of the present disclosure, the stacking fault energy of the steel sheet is controlled by adjusting the content of aluminum (Al), and by this the phase stability of austenite is improved.

[0031] If the stacking fault energy of the steel sheet is appropriate, dislocations and twins in the steel sheet may be harmoniously formed, and thus the phase stability of the steel sheet may be improved. However, if the stacking fault energy is too low, immobile dislocations may be formed to lower the phase stability of the steel sheet, and if the stacking fault energy of the steel sheet is too high, deformation of the steel sheet proceeds only in the form of dislocations to result in the strength of the steel sheet. Therefore, in the embodiment of the present disclosure, an optimal range of stacking fault energy of the steel sheet is proposed so that the steel sheet is provided with appropriate strength and phase stability.

[0032] If the stacking fault energy of the steel sheet is lower than 30 mJ/cm^2, twins may be generated, and thus the strength of the steel sheet may be increased. In this case, however, ε-martensite is formed in the steel sheet. Although ε-martensite has a hexagonal closed packed structure and non-magnetic properties, ε-martensite may be easily transformed into α-martensite. Therefore, for the steel sheet to maintain non-magnetic properties and have a high degree of strength by the formation of twins, the stacking fault energy of the steel sheet is 30 mJ/cm^2 or greater.

[0033] The stacking fault energy of the steel sheet may be measured by various methods such as X-ray measurement methods, transmission electron microscope methods, and thermodynamic calculation methods. For example, a thermodynamic calculation method using thermodynamic data that is easy and effective in reflecting the effects of components may be used to measure the stacking fault energy of the steel sheet.

[0034] In the embodiment of the present disclosure, the steel sheet has a tensile strength of 800 MPa or greater and may have an elongation of 15% or greater. That is, the steel sheet may have high degrees of strength and formability.

[0035] Hereinafter, a method of manufacturing the steel sheet will be described in detail according to an embodiment of the present disclosure.

[0036] A steel slab having the above-described composition is reheated to 1100°C to 1250°C. If the reheating temperature is too low, an excessive load may be applied to the steel slab during a hot-rolling process. Therefore, it may be preferable that the reheating temperature be 1100°C or higher. If the reheating temperature is high, hot-rolling may be easily performed. However, since steel having a high content of manganese (Mn) usually undergoes excessive internal oxidation and deterioration in surface quality, it may be preferable that the upper limit of the reheating temperature of the steel slab be 1250°C.

[0037] After the reheating process, the steel slab is hot-rolled, and then finish-rolled at a temperature range of 800°C to 1000°C so as to form a hot-rolled steel sheet. If the finish rolling (finish hot rolling) is performed at a high temperature, the steel slab may be easily finish-rolled because of low resistance to deformation, but the surface quality of the steel sheet may deteriorate. Therefore, it may be preferable that the finish rolling be performed at 1000°C or lower. On the other hand, if the finish rolling is performed at a too low temperature, an excessive load may be applied to the steel slab. Therefore, the finish rolling is performed at 800°C to 950°C.

[0038] After the hot rolling process, the steel sheet is coiled. The steel sheet is coiled within the temperature range of 400°C to 700°C. After the coiling process, generally, the steel sheet may be cooled at a low cooling rate. A large amount of cooling water may be used to start the coiling process at a low temperature, and in this case, an excessive load may be applied to the steel sheet during cooling. Therefore, the coiling start temperature may be set to be 400°C or higher. If the coiling temperature of the steel sheet is too high, an oxide film formed on the steel sheet may react with the matrix of the steel sheet, and thus the steel sheet may not be easily treated in a later pickling process. Therefore, it may be preferable that the coiling temperature be 700°C or lower.

[0039] Between the hot rolling process and the coiling process, the steel sheet may be water-cooled.

[0040] The steel sheet hot-rolled as described above is cold-rolled to form a cold-rolled steel sheet with a reduction ratio of 30% to 60%. Generally, the reduction ratio of the steel sheet in the cold-rolling process may be determined by the thickness of a final product. In the embodiment of the present disclosure, since recrystallization occurs in the steel sheet during a heat treatment process after the cold-rolling process, a force inducing recrystallization may be appropriately controlled. In detail, if the reduction ratio of the steel sheet in the cold-rolling process is too low, the strength of the steel sheet may be lowered, and thus the reduction ratio may be set to be 30% or higher. On the other hand, if the reduction ratio is too high, the strength of the steel sheet may be increased, but a heavy load may be applied to a rolling mill. Thus, it may be preferable that the reduction ratio be 60% or lower.

[0041] After the cold-rolling process, a continuous annealing process is performed. The continuous annealing process is performed within the temperature range of 650°C to 900°C. Although it is preferable that the continuous annealing process is performed at 650°C or higher for enabling sufficient recrystallization, if the process temperature of the continuous annealing process is excessively high, oxides may be formed on the steel sheet. In addition, the steel sheet may not be processed smoothly with the previous/next steel sheet. Therefore, it is preferable that the continuous annealing process be performed at 900°C or lower.

[Mode for Invention]

[0042] Hereinafter, examples of the present disclosure will be described in detail. The following examples are for illustrative purposes and are not intended to limit the scope and spirit of the present disclosure.

(Embodiment 1)

[0043] Steel slabs having the following compositions were reheated to 1200°C, and a finish hot rolling was performed on the steel slabs at 900°C to form steel sheets. Thereafter, the steel sheets were coiled at 500°C and then cold-rolled with a reduction ratio of 50%. The cold-rolled steel sheets were continuously annealed at 800°C.

[Table 1]

No.	C	Mn	Si	P	S	Al	Ti	B	N
1	0.61	17.96	0.01	0.09	0.004	0.01	0.066	0.002	0.0097
2	0.61	18.30	0.01	0.09	0.003	1.50	0.086	0.002	0.0087
3	0.61	18.50	0.01	0.09	0.003	2.69	0.083	0.003	0.0065
4	0.61	14.54	0.01	0.10	0.005	0.01	0.077	0.002	0.0098
5	0.61	15.10	0.01	0.09	0.006	1.51	0.085	0.002	0.0081
6	0.61	15.54	0.01	0.09	0.005	1.97	0.085	0.002	0.0069
7	0.61	11.58	0.01	0.10	0.005	0.01	0.068	0.002	0.0095
8	0.61	11.63	0.01	0.10	0.006	1.46	0.087	0.002	0.0039
9	0.61	12.41	0.01	0.10	0.004	1. 95	0.092	0.002	0.0069

[0044] The yield strength, tensile strength, and elongation of each of the steel sheets were measured as shown in Table 2 so as to inspect physical properties of the steel sheets.

[Table 2]

No.	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)
1	434.1	1105.6	60.4
2	498.3	960.1	59.3
3	498.8	848.9	49.7
4	509.3	1124.1	51.3
5	479.5	976	57.6

(continued)

No.	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)
6	488.2	938.9	58.4
7	485.6	837.8	16.1
8	491.9	899.5	30.3
9	477.6	914.6	40.7

[0045] In addition, the steel sheets were inspected by measuring the fraction of inclusions, the fraction of carbides according to heat treatment conditions, and relative permeability under a magnetic field of 25 kA/M. The heat treatment conditions were determined by simulating heat treatments that might be performed during a manufacturing process of the steel sheets or the use of the steel sheets.

[0046] The term "relative permeability" refers to the ratio of the permeability of a specific medium to the permeability of vacuum. In the examples, the ratio of the permeability of each of the steel sheets to the permeability of vacuum or air was measured as the relative permeability (μ_r). The measurement was carried out using a vibrating sample magnetometer (VSM) by recording a magnetic field applied to a sample through a Hall probe and electromotive force generated by Faraday's law when the sample was vibrated to measure the magnetization of the sample using the recorded values. VSMs are devices operating according to the above-described operational principle to measure the magnetization of a sample by vibrating the sample to generate electromotive force, detecting the electromotive force using a search coil, and calculating the magnetization of the sample using the electromotive force. VSMs enable simple and rapid measurements of magnetic properties of materials as a function of a magnetic field, temperature, and time within a magnetic flux range up to 2 teslas (T) and a temperature range of 2 K to 1273 K. In addition, various types of samples such as powder, thin films, single crystals, and liquids can be inspected using VSMs, and thus VCMs are widely used for measuring the magnetic properties of materials.

[Table 3]

No.	Heat treatment conditions	Inclusion fraction (%)	Carbide fraction (%)	Relative permeability	Notes
1	400°C, 1hr	0.065	1.18	1.07	*CS1-1
2	400°C, 1hr	0.091	0.57	1.01	**IS1-1
3	400°C, 1hr	0.129	0.08	1.01	IS1-2
4	400°C, 1hr	0.122	1.26	1.09	CS1-2
5	400°C, 1hr	0.108	0.1	1.01	IS1-3
6	400°C, 1hr	0.087	0.05	1.01	IS1-4
7	400°C, 1hr	0.117	1.02	1.07	CS1-3
8	400°C, 1hr	0.075	0.1	1.01	IS1-5
9	400°C, 1hr	0.136	0.01	1.02	IS1-6
1	650°C, 5hrs	0.065	1.35	1.11	CS1-4
2	650°C, 5hrs	0.091	0.85	1.07	CS1-5
3	650°C, 5hrs	0.129	0.14	1.05	IS1-7
4	650°C, 5hrs	0.122	1.47	1.11	CS1-6
5	650°C, 5hrs	0.108	0.46	1.08	CS1-7
6	650°C, 5hrs	0.087	0.25	1.06	CS1-8
7	650°C, 5hrs	0.117	2.12	1.37	CS1-9
8	650°C, 5hrs	0.075	0.91	1.09	CS1-10
9	650°C, 5hrs	0.136	0.51	1.05	IS1-8
*CS: Comparative Sample, **IS: Inventive Sample					

[0047] Referring to Table 3, if a heat treatment is performed at 400°C for 1 hour on steel sheets having a carbide fraction of 1 volume% or less, the permeability of the steel sheets is 1.05 or lower. That is, the steel sheets have good non-magnetic properties. In addition, even though a more severe heat treatment is performed at 600°C for 5 hours on steel sheets having a carbide fraction of 1 volume% or less, the permeability of the steel sheets is less than 1.10.

[0048] Microstructures of Comparative Samples 1-5 and Comparative Samples 1-3 are shown in FIGS. 1A and 1B, respectively. As shown in FIGS. 1A and 1B, Comparative Samples 1-5 have a low carbide fraction, and Comparative Samples 1-3 also not satisfying requirements of the present disclosure have a carbide fraction of greater than 1 volume% and poor non-magnetic properties.

[0049] Thus, it may be understood that a carbide fraction of 1 volume% or less leads to good non-magnetic properties.

(Embodiment 2)

[0050] Steel slabs having the following compositions (weight%) were reheated to 1200°C, and a finish hot rolling was performed on the steel slabs at 900°C to form steel sheets. Thereafter, the steel sheets were coiled at 500°C and then cold-rolled at a reduction ratio of 50%. The cold-rolled steel sheets were continuously annealed at 800°C.

[Table 4]

Sample No.	C	Mn	P	S	Al	Si	Ti	B	N
1	0.61	18.0	0.091	0.004	0.01	0.01	0.0662	0.0021	0.0097
2	0.61	18.3	0.087	0.0034	1.49	0.01	0.0857	0.0023	0.0087
3	0.60	18.3	0.087	0.0024	1.93	0.01	0.0856	0.0023	0.0078
4	0.61	18.5	0.090	0.0027	2.68	0.01	0.0833	0.0025	0.0065
5	0.61	14.5	0.097	0.0051	0.02	0.01	0.0766	0.0021	0.0098
6	0.61	15.1	0.094	0.0055	1.51	0.01	0.0854	0.0024	0.0081
7	0.61	15.5	0.094	0.0049	1.97	0.01	0.0846	0.0024	0.0069
8	0.61	11.6	0.101	0.0053	0.01	0.01	0.0684	0.002	0.0095
9	0.61	11.6	0.102	0.0057	1.45	0.01	0.0868	0.0023	0.0039
10	0.61	12.4	0.098	0.0039	1.94	0.01	0.0915	0.0022	0.0069
11	0.61	18.3	0.092	0.0041	0.51	0.01	0.0662	0.0021	0.0097
12	0.61	18.3	0.092	0.0044	4.52	0.01	0.0833	0.0025	0.0065
13	0.61	18.4	0.091	0.0045	6.02	0.01	0.0766	0.0021	0.0098
14	0.62	18.1	0.092	0.0041	7.513	0.01	0.0854	0.0024	0.0081
15	0.61	14.3	0.096	0.0052	0.51	0.01	0.0846	0.0024	0.0069
16	0.61	14.5	0.097	0.0051	1.01	0.01	0.0684	0.002	0.0095
17	0.62	14.5	0.096	0.0052	4.51	0.01	0.0857	0.0023	0.0087
18	0.62	14.4	0.097	0.0054	6.03	0.01	0.0856	0.0023	0.0078
19	0.61	14.2	0.096	0.0052	7.54	0.01	0.0833	0.0025	0.0065
20	0.61	11.4	0.102	0.0053	0.52	0.01	0.0766	0.0021	0.0098
21	0.62	11.6	0.101	0.0052	1.01	0.01	0.0854	0.0024	0.0081
22	0.61	11.3	0.103	0.0054	1.22	0.01	0.0846	0.0024	0.0069
23	0.62	11.3	0.102	0.0055	4.53	0.01	0.0684	0.002	0.0095
24	0.61	11.4	0.101	0.0052	6.01	0.01	0.0868	0.0023	0.0039

(continued)

Sample No.	C	Mn	P	S	Al	Si	Ti	B	N
25	0.61	11.6	0.101	0.0053	7.51	0.01	0.0915	0.0022	0.0069

[0051] The yield strength (YS), tensile strength (TS), and elongation of each of the cold-rolled steel sheets were measured as shown in Table 2. In addition, the stacking fault energy (SFE) and relative permeability of each of the steel sheets were measured as shown in Table 5. The relative permeability was measured in the same conditions as in Example 1 except that a magnetic field of 50 kA/m was applied.

[Table 5]

Sample No.	YS (MPa)	UTS (MPa)	Elongation (%)	SFE (mJ/m^2)	Relative permeability	Note
1	484.1	1105.6	60.4	24.57	1.07	*CS2-1
2	498.3	960.1	59.3	37.00	1.01	**IS2-1
4	498.8	848.9	49.7	46.68	1.01	IS2-2
5	509.3	1124.1	51.3	20.71	1.06	CS2-2
6	479.5	976	57.6	32.97	1.02	IS2-3
7	488.2	938.9	58.4	36.94	1.02	IS2-4
8	485.6	837.8	16.1	19.97	1.08	CS2-3
9	491.9	899.5	30.3	31.34	1.04	IS2-5
10	477.6	914.6	40.7	35.13	1.02	IS2-6
11	-	-	-	29.11	1.04	CS2-4
12	-	-	-	60.82	1.00	IS2-7
13	-	-	-	72.50	1.00	IS2-8
14	-	-	-	84.07	1.00	IS2-9
15	-	-	-	25.48	1.05	CS2-5
16	-	-	-	28.51	1.05	CS2-6
17	-	-	-	56.02	1.00	IS2-13
18	-	-	-	67.66	1.00	IS2-14
18	-	-	-	79.20	1.00	IS2-15
19	-	-	-	24.60	1.06	CS2-7
20	-	-	-	28.67	1.05	CS2-8
21	-	-	-	29.30	1.04	CS2-9
22	-	-	-	55.03	1.00	IS2-16
23	-	-	-	66.64	1.00	IS2-17
24	-	-	-	78.14	1.00	IS2-18
*CS: Comparative Sample, **IS: Inventive Sample						

[0052] As shown in Table 5, inventive samples of the present disclosure have a stacking fault energy (SFE) of 30 mJ/m^2 or greater and a low degree of relative permeability. That is, the inventive samples have good non-magnetic properties and a high degree of phase stability.

[0053] However, one of the stacking fault energy and relative permeability of each of comparative examples was not satisfactory.

[0054] FIG. 2 is a graph showing XRD curves A and B of Inventive Sample 2-1 and Comparative Sample 2-1, respectively. Curves A and B of FIG. 2 show the phase stability of the samples and effects of the stacking fault energy of the samples. FIGS. 3A and 3B show microstructures of Inventive Sample 1-1 and Comparative Sample 1-1, respectively. Referring to FIGS. 2, 3A, and 3B, it may be understood that the inventive samples of the present disclosure have twins uniformly formed throughout the entire regions thereof and thus high phase stability. However, since the comparative samples have low stacking fault energy, the formation of twins increases after deformation, twins are not present on some crystal surfaces.

Claims

1. A non-magnetic high manganese steel sheet with high strength for heavy electrical machinery, the steel sheet consisting of, by weight%, C: 0.4% to 0.9%, Mn: 10% to 25%, Al: 1.3% to 8.0%, Si: 0.01% to 2.0%, Ti: 0.05% to 0.2%, B: 0.0005% to 0.005%, S: 0.05% or less (excluding 0%), P: 0.8% or less (excluding 0%), N: 0.003% to 0.01%, and the balance of Fe and inevitable impurities, wherein the steel sheet has a stacking fault energy of 30 mJ/cm^2 or more, and wherein the steel sheet has a relative permeability of 1.05 or less in a magnetic field of 50 kA/m, and wherein the steel sheet has a tensile strength of 800 MPa or greater.

2. The steel sheet of claim 1, wherein the steel sheet has a microstructure comprising 1 volume% or less of carbides.

3. The steel sheet of claim 1, wherein the steel sheet has an elongation of 15% or greater.

4. A method of manufacturing a non-magnetic high manganese steel sheet having high strength for heavy electrical machinery, the method comprising:

   reheating a steel slab to a temperature within a range of 1100°C to 1250°C, the steel slab consisting of, by weight%, C: 0.4% to 0.9%, Mn: 10% to 25%, Al: 1.3% to 8.0%, Si: 0.01% to 2.0%, Ti: 0.05% to 0.2%, B: 0.0005% to 0.005%, S: 0.05% or less (excluding 0%), P: 0.8% or less (excluding 0%), N: 0.003% to 0.01%, and the balance of Fe and inevitable impurities;
   performing a hot-rolling process by hot-rolling the reheated steel slab and finish-rolling the steel slab at a temperature within a temperature range of 800°C to 950°C, so as to form a hot-rolled steel sheet;
   coiling the hot-rolled steel sheet at a temperature within a temperature range of 400°C to 700°C;
   cold-rolling the steel sheet with a reduction ratio of 30% to 60%; and
   continuously annealing the cold-rolled steel sheet at a temperature within a temperature range of 650°C to 900°C, wherein the steel sheet has a stacking fault energy of 30 mJ/cm^2 or more, and wherein the steel sheet has a relative permeability of 1.05 or less in a magnetic field of 50 kA/m, and wherein the steel sheet has a tensile strength of 800 MPa or greater.

Patentansprüche

1. Nichtmagnetisches Stahlblech mit hohem Magnesiumgehalt mit hoher Festigkeit für schwere elektrische Maschinen, wobei das Stahlblech in Gew.-% aus Folgendem besteht: C: 0,4 % bis 0,9 %, Mn: 10 % bis 25 %, Al: 1,3 % bis 8,0 %, Si: 0,01 % bis 2,0 %, Ti: 0,05 % bis 0,2 %, B: 0,0005 % bis 0,005 %, S: bis zu 0,05 % (aber nicht 0 %), P: bis zu 0,8 % (aber nicht 0 %), N: 0,003 % bis 0,01 %, der Rest sind Eisen und unvermeidbare Verunreinigungen, wobei das Stahlblech eine Stapelfehlerenergie von wenigstens 30 mJ/cm^2 aufweist und wobei das Stahlblech eine relative Permeabilität von bis zu 1,05 in einem Magnetfeld von 50 kA/m aufweist und wobei das Stahlblech eine Zugfestigkeit von wenigstens 800 MPa aufweist.

2. Stahlblech nach Anspruch 1, wobei das Stahlblech eine Mikrostruktur aufweist, die höchstens 1 Vol.-% Carbide umfasst.

3. Stahlblech nach Anspruch 1, wobei das Stahlblech eine Streckung von wenigstens 15 % aufweist.

4. Verfahren zum Erzeugen eines nichtmagnetischen Stahlblechs mit hohem Magnesiumgehalt mit hoher Festigkeit für schwere elektrische Maschinen, wobei das Verfahren Folgendes umfasst:

erneutes Erwärmen einer Stahlbramme auf eine Temperatur in einem Bereich von 1 100 °C bis 1 250 °C, wobei die Stahlbramme in Gew.-% aus Folgendem besteht: C: 0,4 % bis 0,9 %, Mn: 10 % bis 25 %, Al: 1,3 % bis 8,0 %, Si: 0,01 % bis 2,0 %, Ti: 0,05 % bis 0,2 %, B: 0,0005 % bis 0,005 %, S: bis zu 0,05 % (aber nicht 0 %), P: bis zu 0,8 % (aber nicht 0 %), N: 0,003 % bis 0,01 %, der Rest sind Eisen und unvermeidbare Verunreinigungen;
Ausführen eines Warmwalzvorgangs durch Warmwalzen der erneut erwärmten Stahlbramme und Glattwalzen der Stahlbramme bei einer Temperatur innerhalb eines Temperaturbereichs von 800 °C bis 950 °C, um ein warmgewalztes Stahlblech auszubilden;
Abkühlen des warmgewalzten Stahlblechs auf eine Temperatur innerhalb eines Temperaturbereichs von 400 °C bis 700 °C;
Kaltwalzen des Stahlblechs mit einem Reduktionsverhältnis von 30 % bis 60 %; und
kontinuierliches Glühen des kaltgewalzten Stahls bei einer Temperatur innerhalb eines Temperaturbereichs von 650 °C bis 900 °C,
wobei das Stahlblech eine Stapelfehlerenergie von wenigstens 30 mJ/cm^2 aufweist und wobei das Stahlblech eine relative Permeabilität von bis zu 1,05 in einem Magnetfeld von 50 kA/m aufweist und wobei das Stahlblech eine Zugfestigkeit von wenigstens 800 MPa aufweist.

Revendications

1. Tôle d'acier riche en manganèse non magnétique de haute tenue mécanique pour grosse machinerie électrique, la tôle d'acier consistant en, en % en poids, C : 0,4 % à 0,9 %, Mn : 10 % à 25 %, Al : 1,3 % à 8,0 %, Si : 0,01 % à 2,0 %, Ti : 0,05 % à 0,2 %, B : 0,0005 % à 0,005 %, S : 0,05 % ou moins (à l'exclusion de 0 %), P : 0,8 % ou moins (à l'exclusion de 0 %), N : 0,003 % à 0,01 %, et le solde étant du Fe et des impuretés inévitables, dans laquelle la teneur d'acier a une énergie de défaut d'empilement de 30 mJ/cm^2 ou plus, et dans laquelle la tôle d'acier a une perméabilité relative de 1,05 ou moins dans un champ magnétique de 50 kA/m, et dans laquelle la tôle d'acier a une résistance à la traction de 800 MPa ou plus.

2. Tôle d'acier selon la revendication 1, dans laquelle la tôle d'acier a une microstructure comprenant 1 % en volume ou moins de carbures.

3. Tôle d'acier selon la revendication 1, dans laquelle la tôle d'acier a un allongement de 15 % ou plus.

4. Procédé de fabrication d'une tôle d'acier riche en manganèse non magnétique ayant une haute tenue mécanique pour grosse machinerie électrique, le procédé comprenant :

   le réchauffage d'une brame d'acier à une température dans une plage de 1 100 °C à 1 250 °C, la brame d'acier consistant en, en % en poids : C : 0,4 % à 0,9 %, Mn : 10 % à 25 %, Al : 1,3 % à 8,0 %, Si : 0,01 % à 2,0 %, Ti : 0,05 % à 0,2 %, B : 0,0005 % à 0,005 %, S : 0,05 % ou moins (à l'exclusion de 0 %), P : 0,8 % ou moins (à l'exclusion de 0 %), N : 0,003 % à 0,01 %, et le solde étant du Fe et des impuretés inévitables ;
   la réalisation d'un processus de laminage à chaud par laminage à chaud de la brame d'acier réchauffée et d'un brunissage de finition de la brame d'acier à une température dans une plage de température de 800 °C à 950 °C, de manière à former une tôle d'acier laminée à chaud ;
   le bobinage de la tôle d'acier laminée à chaud à une température dans une plage de température de 400 °C et 700 °C ;
   le laminage à froid de la tôle d'acier avec un rapport de réduction de 30 % à 60 % ; et
   le recuit continu de la tôle d'acier laminée à froid à une température dans une plage de température de 650 °C à 900 °C,
   dans lequel la tôle d'acier a une énergie de défaut d'empilement de 30 mJ/cm^2 ou plus, et dans lequel la tôle d'acier a une perméabilité relative de 1,05 ou moins dans un champ magnétique de 50 kA/m, et dans lequel la tôle d'acier a une résistance à la traction de 800 MPa ou plus.

【Figure 1】

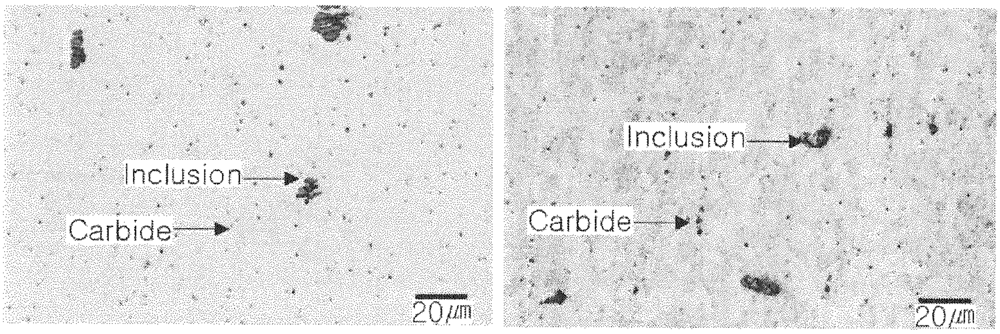
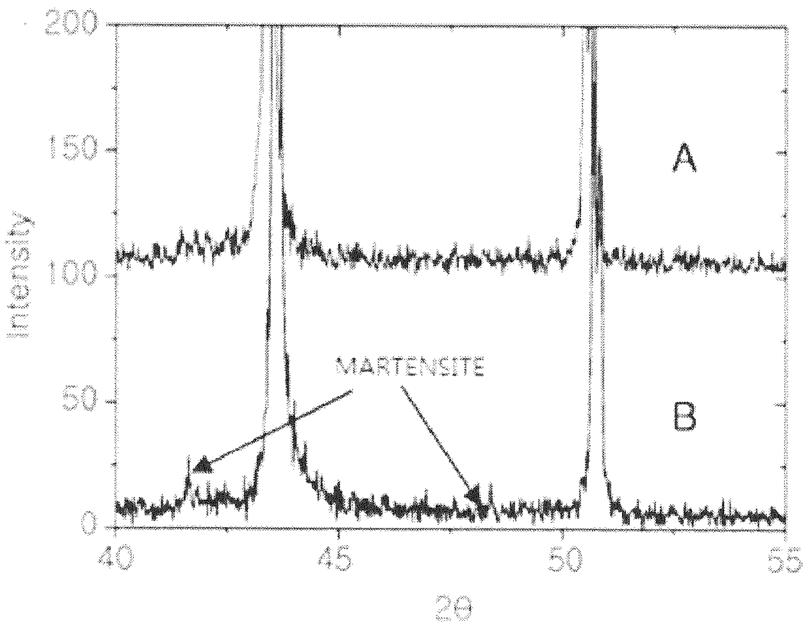


FIG. 1A FIG. 1B

【Figure 2】



【Figure 3】

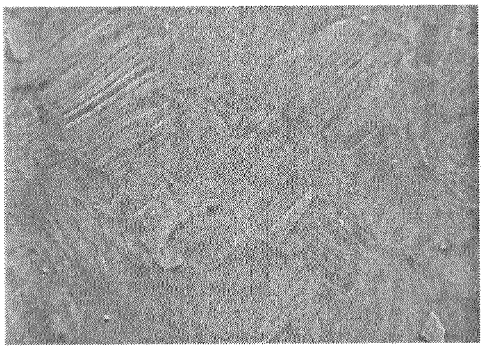


FIG. 3A

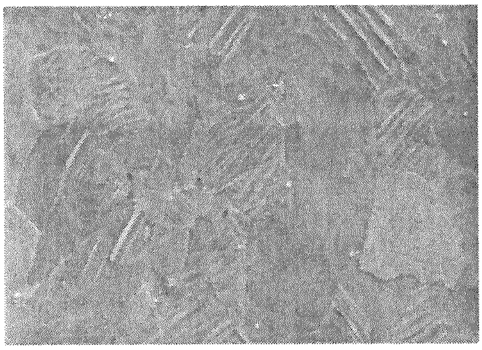


FIG. 3B

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- WO 2007075006 A1 **[0005]**
- WO 2008078940 A1 **[0005]**
- KR 20090070510 A **[0006]**
- JP H07126809 A **[0007]**
- WO 2009084793 A1 **[0008]**
- KR 20090070507 A **[0009]**