(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
22 May 2025 (22.05.2025)

WIPO | PCT

(10) International Publication Number
WO 2025/104641 A1

(51) International Patent Classification:
C22C 38/02 (2006.01) *C21D 9/46* (2006.01)
C22C 38/04 (2006.01) *C21D 8/12* (2006.01)
C22C 38/06 (2006.01) *C21D 6/00* (2006.01)
C22C 38/00 (2006.01) *C21D 1/26* (2006.01)
C22C 38/08 (2006.01)

(21) International Application Number:
PCT/IB2024/061336

(22) International Filing Date:
14 November 2024 (14.11.2024)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
PCT/IB2023/061521
15 November 2023 (15.11.2023) IB

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*
— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

(54) Title: A NON-ORIENTED ELECTRICAL STEEL AND A METHOD OF MANUFACTURING NON-ORIENTED ELECTRICAL STEEL THEREOF

(57) Abstract: The invention deals with a non-oriented electrical steel sheet having a composition comprising of the following elements, expressed in percentage by weight: 0.0001% ≤ Carbon ≤ 0.009 % 0.25% ≤ Manganese ≤ 0.6% 1% ≤ Silicon ≤ 2.5% 0.15% ≤ Aluminum ≤ 0.3 % 0.05% ≤ Tin≤ 0.15% Phosphorus ≤ 0.15 % Sulfur ≤ 0.006% Nitrogen ≤ 0.09% and can contain one or more of the following optional elements 0% ≤ Niobium ≤ 0.1% 0% ≤ Titanium ≤ 0.1% 0% ≤ Vanadium ≤ 0.1% 0% ≤ Chromium ≤ 1% 0% ≤ Molybdenum ≤ 0.5% 0% ≤ Tungsten≤ 0.1% 0% ≤ Cobalt ≤ 1% 0% ≤ Arsenic ≤ 0.05% 0.001% ≤ Calcium ≤ 0.01% 0% ≤ Copper ≤ 1% 0% ≤ Nickel ≤ 1% 0 % ≤ Boron ≤ 0.05% 0 % ≤ Lead ≤ 0.2% 0% ≤Antimony ≤ 0.2% the remainder composition being composed of iron and unavoidable impurities caused by processing, the microstructure of said steel sheet being made of ferrite and comprising in area fraction, 80% to 100% recrystallized microstructure, 0% to 20% non-recrystallized microstructure wherein the average grain size of recrystallized microstructure is from 20 microns to 110 microns and having a percentage of eddy current losses in total iron losses, measured at 1 T and 400 Hz according to IEC 60404-2 standards, from 35% to 50% when calculated in accordance of Bertotti method.

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A NON-ORIENTED ELECTRICAL STEEL AND A METHOD OF MANUFACTURING NON-ORIENTED ELECTRICAL STEEL THEREOF

The present invention relates to a non-oriented electrical steel sheet and a manufacturing method thereof. Specifically, the present invention relates to a non-oriented electrical steel sheet and a manufacturing method thereof that have low iron losses specifically a low eddy current loss while having good mechanical properties.

Therefore, intense research and development endeavors are put in higher performance properties have been required for a non-oriented electrical steel sheet to be used as an iron core material of a electrical machine due to a worldwide increase in achievement of energy saving of an electrical apparatus. Recently in particular, as a motor to be used for an electric vehicle or the like, a demand for a small-sized high-power motor has been high. Such an electric vehicle motor has been designed to make high-speed rotation possible to thereby obtain high torque while having lowest possible losses. This requires light and highly efficient non oriented electrical steels which have low losses as their key property. Finding the balance between losses, permeability, polarisation, thermal conductivity, tensile strength and yield strength, is vital for non-oriented electrical steels.

The lower the iron losses in the electric machine, the higher its efficiency, hence to reduce the quantity of the iron losses in an electrical machine the manufacturers of the electrical machines have several options, whereby their principal options are to reduce either the hysteresis losses or the eddy current losses to improve the efficiency of their electrical machine. Advances are frequently achieved by a combination of the two approaches. This invention relates to the second option, namely the reduction of eddy current losses for an electrical machine. there is two-track alternatives to reduce the eddy current losses:

The first track consists of reducing the thicknesses of the steel sheets used in the electrical machines such as to have the thickness of the steel sheet below 0.35mm or even lower. Unfortunately, this solution has its limits on account of a reduction in the stacking factor which decreases the torque achievable for a given machine height and further a prohibitive decrease in the rigidity of certain automotive parts and the appearance of acoustical problems that create uncomfortable conditions for the passenger.

The second track consists of optimizing the elemental composition of the steel sheet such as by increase the amount of alloying elements to restrict the eddy current losses. Among these alloying

elements such as, the Aluminum and Manganese ones have attractive mechanical and magnetic properties while making it possible to significantly reduce the eddy current losses. However, addition of alloying elements can be done up to a limit because after a certain percentage presence alloying elements will impacts the hysteresis losses and the magnetic polarization.

Earlier research and developments in the field of high strength non-oriented electrical steel have resulted in several methods for producing high strength non-oriented electrical steel, some of which are enumerated herein for conclusive appreciation of the present invention:

US2021/371948 is non - oriented electrical steel sheet with an average magnetostriction λp - p at 400 Hz and 1.0 T of not more than $4.5x10^{-6}$, and area ratio of recrystallized grains at a section in rolling direction of steel sheet of 40 to 95 % and an average grain size of 10 to 40 microns is obtained by subjecting a steel slab containing , in mass % , C : not more than 0.005 % , Si : 2.8 to 6.5 % , Mn : 0.05 to 2.0% , Al : not more than 3.0 % , P : not more than 0.20 % , S : not more than 0.005 % , N : not more than 0.005 % , Ti : not more than 0.003 % , V : not more than 0.005 % and Nb : not more than 0.005 % and satisfying Si - 2A1 - Mn≥0 to hot rolling , hot - band annealing , cold rolling and finish annealing under adequate cold rolling and finish annealing conditions , and a motor core is manufactured by such a steel sheet. US2021/371948 does not demonstrate the total elongation and eddy current loss at all.

The purpose of the present invention is to solve these problems by making non-oriented electrical steel sheets that have a percentage of eddy current loss in total iron loss of from 35% to 50% and preferably from 38% to 48% when calculated in accordance with Bertotti method.

In preferred embodiments, the additional following properties can be also reached, alone or in combination :

- an ultimate tensile strength of 380MPa or more in both transversal direction as well as rolling direction and preferably more than 400MPa in both transversal direction as well as rolling direction. In another embodiment, the ultimate tensile strength remains below 500 MPa in both transversal direction as well as rolling direction.
- a yield strength from 250MPa or more in both transversal direction as well as rolling direction and preferably from 270MPa or more in both transversal direction as well as rolling direction

- a total elongation of 20% or more in both transversal direction as well as rolling direction and preferably more than or equal to 22% in both transversal direction as well as rolling direction
- a magnetic polarization at 5000A/m (J50) from 1.66T to 1.80T and preferably a magnetic polarization at 5000A/m (J50) from 1.70T to 1.79Tand more preferably a magnetic polarization at 5000A/m (J50) from 1.72T to 1.78T.
- a total loss from 17 to 23W/kg when measured at 1T and 400Hz and preferably from 18 to 22W/kg when measured at 1T and 400Hz and more preferably 19 to 21W/kg when measured at 1T and 400Hz

Preferably, such steel can also have a good suitability for rolling with good punchability and coatability.

Preferably, a hardness greater than or equal to 185HV and preferably hardness greater than or equal to 195HV.

Another object of the present invention is also to make available a method for the manufacturing of these sheets that is compatible with conventional industrial applications while being robust towards manufacturing parameters shifts.

The above object and other advantages of the present invention will become more apparent by describing in detail the preferred embodiment of the present invention.

The chemical composition of the non-oriented electrical steel comprises of the following elements, in weight percent:

Carbon is present in the steel of present invention is from 0.0001% to 0.009%. Carbon is a precipitate forming element that is why detrimental for the magnetic properties of the present steel. Hence the presence of Carbon in the present steel is from 0.0001% to 0.009%. Since the Carbon promotes magnetic aging the preferred content of Carbon according to the present invention is from 0.002% to 0.008% and more preferably from 0.005% to 0.008%.

Manganese content of the steel of present invention is from 0.25% to 0.6%. Manganese provides solid solution strengthening and reducing the iron loss by increasing specific resistance. When

the addition of manganese amount is above 0.6%, the magnetic flux density may be considerably reduced, and recrystallization of the steel will be hindered during annealing. The preferred limit for the presence of Manganese is from 0.26% to 0.5% and more preferably 0.26% to 0.4%.

Silicon content of the steel of present invention is from 1% to 2.5%. Silicon is an element that contributes to increasing the strength by solid solution strengthening and is a key element to reduce eddy current loss of iron loss by increasing specific resistance of steel. The mentioned effects requires a minimum Silicon content of at least 1%. However, when silicon content is in an amount exceeding 2.5% causes the rolling to be difficult and the magnetic induction of the steel will be significantly lowered. The preferred limit for the presence of Silicon is from 1.1% to 2.4% and more preferably from 1.2% to 2.3% and even better to have Silicon from 1.2% to 1.5%.

The content of the Aluminum is from 0.15% to 0.3%. Aluminum increases the electrical resistivity of the material and can effectively reduce the iron loss of steel. When the content of Aluminum is present more than 0.3%, the magnetic induction of the steel will be significantly reduced, and it is also detrimental to the rollability of cold rolling of the steel of present invention. The preferred limit for the presence of Aluminium is from 0.16% and 2.4% and more preferably from 0.17% to 0.23%. Tin is an essential element of the steel of this invention and is present from 0.05% to 0.15%. It plays a beneficial role on magnetic properties, especially the polarization and magnetic induction in particular through improvement of the texture. Below 0.05% of tin, the effect is negligible and above 0.15%, steel brittleness will become an issue which increases the risk of breakage at the time when the steel sheet is running during Cold rolling and continuous annealing. Additionally the growth of grains is also hampered and thereby deteriorating magnetic properties. The preferred limit for the presence of Tin is from 0.06% and 0.14% and more preferably from 0.08% to 0.11%.

Sulfur is not an essential element but may be contained as an impurity in steel and from point of view of the present invention the Sulfur content is preferably as low as possible but 0.006% or less from the viewpoint of manufacturing cost. Further if higher Sulfur is present in steel it combines to form Sulfides which are detrimental for the magnetic properties of the present invention.

Phosphorus constituent of the Steel of present invention is from 0% to 0.15%, Phosphorus reduces the hot and cold ductility, particularly due to its tendency to segregate at the grain

boundaries or co-segregate with Manganese. For these reasons, its content is limited to 0.15% and preferably from 0.1% to 0.13%.

Nitrogen is limited to 0.09% to minimize the precipitation of Aluminum nitrides during solidification which are detrimental for magnetic properties of the steel.

Titanium is an optional element and when added to the Steel of present invention is from 0% to 0.1%. It forms Titanium-nitrides appearing during solidification of the cast product. The amount of Titanium is so limited to 0.1% to avoid the formation of Titanium-nitrides detrimental for magnetic properties of the steel of present invention. In case the Titanium content below 0.001% does not impart any effect on the steel of present invention.

Niobium is present in the Steel of present invention from 0% to 0.1% and suitable for forming carbo-nitrides to increase strength of the Steel of present invention by precipitation hardening. Niobium will also impact the size of microstructural components through its precipitation as carbo-nitrides. However, Niobium content above 0.1% is not economically interesting as a saturation effect.

Vanadium is present in the Steel of present invention from 0% to 0.1% and is effective in enhancing the strength of steel by forming carbides or carbo-nitrides and the upper limit is 0.1% from economic points of view.

Chromium is an optional element for the steel of present invention is from 0% to 1%. Chromium provide strength to the steel by solid solution strengthening but when used above 1% impairs the magnetic properties of the steel.

Molybdenum is an optional element that constitutes 0% to 0.5% of the Steel of present invention. Mo has an effect of coarsening carbide and thus reducing the iron loss. When it exceeds 0.5%, the effect of improving the iron loss is saturated.

Tungsten is an optional element that constitutes 0% to 0.1% of the Steel of present invention. Tungsten has an effect of coarsening carbide and reducing the iron loss, like Mo. However, when the addition amount is less than 0.001 mass%, the above effect cannot be obtained sufficiently, while when it exceeds 0.1 wt.%, the effect of improving the iron loss is saturated.

Cobalt is an optional element that constitutes 0% to 1% of the Steel of present invention. Cobalt is an element increasing the magnetic moment of Fe alloy and has an effect of increasing a magnetic flux density and reducing the iron loss. However, when the addition amount is less than 0.01 wt.%, the above effects cannot be obtained sufficiently, while when it exceeds 1 wt.%, the raw material cost is largely increased.

Arsenic is an optional element that constitutes 0% to 0.05% of the Steel of present invention. As is a grain boundary segregation element and has an effect of improving the texture and thus reducing the iron loss. The above effect is obtained by the addition of not less than 0.001 wt.%. However, As is an element causing grain boundary embrittlement, and this adverse effect becomes particularly remarkable when it is added by more than 0.05 wt.%. Therefore, As is preferable to be added within the range of 0.001 to 0.05 wt.%

Nickel may be added as an optional element in an amount of 0% to 1% to increase the strength of the steel present invention and to improve its strength and elongation. However, when its content is above 1%, Nickel causes ductility deterioration. In a preferred embodiment, nickel content remains below 0.04%. In another embodiment, nickel content is at least 0.01% and even better nickel content is from 0.01 to 0.4%.

Copper may be added as an optional element in an amount of 0% to 1% to increase the strength and elongation of the of Steel of present invention. However, when its content is above 1%, it can degrade the surface aspects.

Boron is an optional element for the steel of present invention and may be present from 0% to 0.05%. Boron forms boro-nitirides and impart additional strength to steel of present invention when added in an amount of at least 0.0001%.

Calcium may be present in the steel of present invention optionally and may be from 0.001% to 0.01%. Calcium contributes towards the refining of the Steel by binding the detrimental Sulfur content in globular form thereby retarding the harmful effect of Sulfur.

Other elements such as Pb or Sb can be added individually or in combination in the following proportions: Pb $\leqq$0.2% and Sb $\leqq$0.2%. Up to the maximum content levels indicated, these

elements make it possible to refine the grain during solidification. In a preferred embodiment, Sn content is below 0.04%.

The remainder of the composition of the steel consists of iron and inevitable impurities resulting from processing.

The microstructure of the non-oriented electrical steel will now be described in detail, all percentages being in area fraction.

The microstructure is made of ferrite. The steel of present invention has a recrystallized microstructural region from 80% to 100% in area fraction with grains having an average grain size from 20 microns to 110 microns. The recrystallized structure with a high degree of recrystallization is due to the homogenous Silicon enrichment which improves magnetic properties of the steel of present invention. A controlled grain size ensures the mechanical properties in both transverse and rolling direction. The preferred degree of recrystallization is from 90% to 100%. The preferred an average grain size for the present invention is from 20 microns to 100 microns and more preferably from 20 microns to 90 microns.

The steel of present invention may have a non-recrystallized microstructural region from 0% to 20% in area fraction and the preferred degree of non-recrystallization is from 0% to 10% and more preferably from 0% to 5%

In addition to the above-mentioned microstructure, the microstructure of the non-oriented electrical steel is free from microstructural components such as martensite, bainite, pearlite and cementite.

The steel according to the invention can be manufactured by any suitable methods. It is however preferable to use the method according to the invention that will be detailed, as a non-limitative example.

Such preferred method consists in providing a semi-finished casting of steel with a chemical composition of the steel according to the invention. The casting can be done either into ingots or continuously in form of thin slabs or thin strips, i.e. with a thickness ranging from approximately 240mm or less for any form of casting.

For example, the cast in form of a slab is casted with the chemical composition according to the invention and then it is reheated, the Slab Reheating Temperature lying from 1050°C to 1250°C until the temperature is homogeneous through the whole slab. Below 1050°C, rolling becomes difficult and forces on the mill will be too high. Above 1250°C, high silicon grades become very soft and might show some sagging and thus become difficult to handle. Preferably, the slab reheating temperature is from 1150°C to 1250°C and more preferably from 1160°C to 1220°C

Subjecting the reheated slab to hot rolling wherein the hot rolling finishing temperature plays a role on the final hot rolled microstructure and takes place from 870°C to 1000°C. When the Finishing Rolling Temperature is below 870°C, recrystallization is limited and the microstructure is highly deformed. Above 1000°C would mean more impurities in solid solution and possible consequent precipitation and deterioration of magnetic properties as well. Preferably, the Finishing Rolling Temperature is from 880°C to 980°C and more preferably from 890°C to 950°C.

The hot rolled steel sheet obtained in this manner is then cooled immediately at a cooling rate of at least 10°C/s to the Coiling Temperature of the hot rolled steel sheet which also plays a role on the hot rolled steel sheet; it takes place from 625°C to 750°C. Coiling at temperatures below 625°C will not have the proper distribution and size of the precipitates for the steel of present invention. Above 750°C, a thick oxide layer would appear, and it will cause difficulties for subsequent processing steps such as cold rolling and/or pickling. Preferably, the cooling rate will be less than or equal to 200° C/s and more preferably the cooling rate is from 12°C/s to 75°C/s. Preferably, the Coiling Temperature is from 650°C to 725°C and more preferably from 660°C to 710°C.

The coiled hot rolled steel sheet is then cooled down to room temperature before subjecting it to optional hot band annealing.

The hot rolled steel sheet may be subjected to an optional scale removal step to remove the scale formed during the hot rolling before optional hot band annealing. The hot rolled sheet then be subjected to an optional hot band annealing such hot band annealing is performed at temperatures from 650°C to 1100°C, preferably for at least 10 seconds and not more than 96 hours, the temperature preferably remaining from 700°C to 1070°C and more preferably from 720°C to 1050°C. Thereafter, an optional scale removal step of this hot rolled steel sheet may be performed through, for example, pickling of such sheet.

Thus, the hot rolled steel sheet obtained may optionally have thickness from 0.8mm to 3.5mm and preferably from 0.9mm to 3mm and more preferably 1mm to 2.8mm.

This hot rolled steel sheet is then subjected to cold rolling to obtain a cold rolled steel sheet with a thickness reduction from 50 to 95%. Preferably, the thickness reduction from 60% to 95% and more preferably from 75% to 95%.

Thereafter the cold rolled steel sheet is being heat treated which will impart the steel of present invention with requisite mechanical properties and microstructure.
The cold rolled steel sheet is then heated wherein the heating starts from room temperature, the cold rolled steel sheet being heated, at a heating rate HR1 of at least 1°C/s, to an annealing temperature Tsoak which is from 900°C to 1150°C, preferably from 950°C to 1100°C and more preferably from 990°C to 1050°C . In a preferred embodiment, the heating rate HR1 for heating is at least 2°C/s and more preferably at least 5°C/s.

The cold rolled steel sheet is held at Tsoak during 10 seconds to 5000 seconds to ensure a recrystallization from 80% to 100%.

The cold rolled steel sheet is then cooled wherein cooling starts from Tsoak, the cold rolled steel sheet being cooled down, at a cooling rate CR1 from 1°C/s to 150°C/s, to a temperature T1 which is in a range from 20°C to 300°C. In a preferred embodiment, the cooling rate CR1 is from 3°C/s to 120°C/s. The preferred T1 temperature is from 20°C to 200°C.

The cold rolled steel sheet thus obtained has a thickness from 0.26mm to 0.32mm and more preferably from 0.27 mm to 0.32 mm and even more preferably from 0.27mm to 0.31 mm.

Then, the cold rolled steel sheet is cooled down to room temperature to obtain a non-oriented electrical steel sheet.

The non-oriented electrical steel sheet of the present invention may optionally be coated with insulation, organic coating or inorganic coating or combination of to improve isolation.

EXAMPLES

The following tests, examples, figurative exemplification and tables which are presented herein are non-restricting in nature and must be considered for purposes of illustration only and will display the advantageous features of the present invention.

Steel sheets made of steels with different compositions are gathered in Table 1, where the steel sheets are produced according to process parameters as stipulated in Table 2, respectively. Thereafter, table 3 gathers the result of evaluations of obtained properties.

All steels of Table 1 had a nitrogen content below 0.09%.

Table 2 gathers the hot rolling and annealing process parameters implemented on cold rolled steel sheets to impart the steels of table 1 with requisite mechanical and magnetic properties to become a non-oriented electrical steel. All the Inventive steels that is from I1 and I2 are cooled after hot rolling at cooling rate of 15°C/s. Further for the inventive examples the Cold rolling reduction is 80% and thereafter the heating rate HR1 to the annealing soaking temperature is 5°C/s. The T1 temperature for all the inventive examples is 25°C while the cooling rate CR1 is at 5°C/s.

All steels produced according to table 2 parameters showed a recrystallized microstructure with more than 95% of recrystallization and with a grain size from 20 to 110 µm.

Table 1 :

Steel	C	Mn	Si	Al	Sn	S	P	Ni
I1	0.0062	0.276	1.26	0.185	0.094	0.0037	0.126	0.0156
I2	0.0062	0.277	1.27	0.186	0.094	0.0037	0.126	0.0156

Table 2 :

Trials	Reheating (°C)	FRT (°C)	Coiling (°C)	HBA(°C)	HBA time(hours)	Reduction (%)	Tsoak (°C)	Annealing time(s)	Cold rolled Thickness(mm)
I1	1186	897	697	840	12	85	1000	16	0.273
I2	1186	897	697	840	12	80	1000	16	0.302

Table 3

The results of the various mechanical tests conducted in accordance with the standards are gathered. The ultimate tensile strength, total elongation and yield strength are measured in accordance with NF EN ISO 6892-1 standards and the J50 magnetic properties and the total iron losses at 1T and 400Hz were measured in accordance with IEC 60404-2 standards. The Eddy current losses are calculated in accordance with the Bertotti Method published in the paper entitled as "General Properties of Power Losses in Soft Ferromagnetic Materials" by Giorgio Berttoti published in IEEE TRANSACTIONS ON MAGNETICS, Vol. 24, No.1 of January 1988. The Equation 2 identifies classical losses which is designated by (P^{class}) which for the purpose of this invention is referred to as Eddy current losses.

The average grain size of the recrystallized microstructure is measured in accordance with ASTM E112 96(02) standards with linear intercept method.

Trials	Tensile Strength (MPa)		Yield Strength (MPa)		Total Elongation (%)		J50 (T)	P1T/400 Hz (W/Kg)	% of Eddy current losses
	RD	TD	RD	TD	RD	TD			
I1	408	424	274	278	22.68	31.85	1.748	19.31	39.6
I2	408	424	274	278	22.68	31.85	1.747	20.32	45.6

CLAIMS

1. A non-oriented electrical steel sheet having a composition comprising of the following elements, expressed in percentage by weight:

0.0001% ≤ Carbon ≤ 0.009 %

0.25% ≤ Manganese ≤ 0.6%

1% ≤ Silicon ≤ 2.5%

0.15% ≤ Aluminum ≤ 0.3 %

0.05% ≤ Tin≤ 0.15%

Phosphorus ≤ 0.15 %

Sulfur ≤ 0.006 %

Nitrogen ≤ 0.09%

and can contain one or more of the following optional elements

0% ≤ Niobium ≤ 0.1%

0% ≤ Titanium ≤ 0.1%

0% ≤ Vanadium ≤ 0.1%

0% ≤ Chromium ≤ 1%

0% ≤ Molybdenum ≤ 0.5%

0% ≤ Tungsten≤ 0.1%

0% ≤ Cobalt ≤ 1%

0% ≤ Arsenic ≤ 0.05%

0.001% ≤ Calcium ≤ 0.01%

0% ≤ Copper ≤ 1%

0% ≤ Nickel ≤ 1%

0 % ≤ Boron ≤ 0.05%

0 % ≤ Lead ≤ 0.2%

0% ≤Antimony ≤ 0.2%

the remainder composition being composed of iron and unavoidable impurities caused by processing, the microstructure of said steel sheet being made of ferrite and comprising in area fraction, 80% to 100% recrystallized microstructure, 0% to 20% non-recrystallized microstructure wherein the average grain size of recrystallized microstructure is from 20 microns to 110microns and having a percentage of eddy current losses in total iron losses, measured at 1 T and 400 Hz according to IEC 60404-2 standards, from 35% to 50% when calculated in accordance of Bertotti method.

2. Non-oriented electrical steel sheet according to claim 1, wherein the composition includes 1.1% to 2.4% of Silicon.

3. Non-oriented electrical steel sheet according to anyone of claims 1 or 2, wherein the composition includes 0.002% to 0.008% of Carbon.

4. Non-oriented electrical steel sheet according to claims 1 to 3, wherein the composition includes 0.16% to 0.24% of Aluminum.

5. Non-oriented electrical steel sheet according to anyone of claims 1 to 4, wherein the composition includes 0.25% to 0.5% of Manganese.

6. Non-oriented electrical steel sheet according to anyone of claims 1 to 5, wherein the amount of non-recrystallized microstructure is from 0% to 10%.

7. Non-oriented electrical steel sheet according to anyone of claims 1 to 6, wherein the amount of recrystallized microstructure is from 90% to 100%.

8. Non-oriented electrical steel sheet according to anyone of claims 1 to 7, wherein said steel sheet has an ultimate tensile strength of at least 380 MPa in both transversal direction as well as rolling direction.

9. Non-oriented electrical steel sheet according to anyone of claims 1 to 8 having a yield strength from 250 MPa or more in both transversal direction as well as rolling direction.

10. Non-oriented electrical steel sheet to anyone of claims 1 to 9, wherein said steel sheet has a total elongation of at least 20% in both transversal direction as well as rolling direction.

11. A method of production of a non-oriented electrical steel sheet according to anyone of claims 1 to 10 comprising the following successive steps:
    - providing a steel composition according to anyone of claims 1 to 5;
    - reheating said semi-finished product to a temperature from 1050°C to 1250°C;
    - rolling the said semi-finished product wherein the hot rolling finishing temperature shall be from 870°C to 1000°C to obtain a hot rolled steel sheet.
    - cooling the hot rolled sheet immediately after the finishing of hot rolling
    - then the hot rolled steel sheet is cooled from finishing of hot rolling to a coiling temperature range which is from 625°C to 750°C at a cooling rate of at least 10°C/s
    - thereafter coiling the hot rolled steel sheet in the coiling temperature range from 625°C to 750°C
    - optionally performing scale removal process on said hot rolled steel sheet;
    - optionally hot band annealing is performed on hot rolled steel sheet from 650°C to 1100°C during 10 seconds to 96 hours;
    - optionally performing scale removal process on said hot rolled steel sheet;

- cold rolling the said hot rolled steel sheet with a reduction rate from 50 to 95% to obtain a cold rolled steel sheet;
- thereafter annealing the said cold rolled steel sheet wherein the heating for annealing starts from room temperature to an annealing temperature range Tsoak which is from 900°C to 1150°C, with a heating rate HR1 of at least 1°C/s,
- then perform annealing at annealing temperature during 10 to 5000 seconds,
- then cooling the cold rolled steel sheet which starts from the annealing temperature to a temperature T1 from 300°C to 20°C, with a cooling rate CR1 from 1°C/s to 150°C/s
- then cooling to room temperature to obtain a non-oriented electrical steel sheet .

12. A method according to claim 11, wherein the Tsoak temperature for annealing is from 950°C to 1100°C.

13. A method according to claim 11 or 12, wherein temperature T1 is from 200°C to 20°C.

14. A method according to anyone of claims 11 to 13, wherein the cooling rate CR1 is from 3°C/s to 120°C/s.

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2024/061336

A. CLASSIFICATION OF SUBJECT MATTER

INV. C22C38/02 C22C38/04 C22C38/06 C22C38/00 C22C38/08
C21D9/46 C21D8/12 C21D6/00 C21D1/26
ADD.

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)
C22C C21D

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. 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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X	WO 93/08313 A1 (PO HANG IRON & STEEL [KR]; RES INST IND SCIENCE & TECH [KR]) 29 April 1993 (1993-04-29) paragraphs [0020] - [0043], [0054] - [0056] tables 1-20 claims 1-32	1-14
X	KR 101 701 195 B1 (POSCO [KR]) 1 February 2017 (2017-02-01) the whole document	1-14

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 February 2025	21/02/2025

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Vlassi, Eleni

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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	WO 02/052048 A1 (USINOR [FR]; HERNANDEZ JACQUES [FR]; AMELOT PASCAL [FR]) 4 July 2002 (2002-07-04) claims 1-15 pages 1-11	1-14
A	US 2013/167987 A1 (KIM JAE-SONG [KR] ET AL) 4 July 2013 (2013-07-04) claims 1-19 tables 1-10 paragraphs [0007] - [0097]	1-14
A	CN 105 256 227 A (WUHAN IRON & STEEL GROUP CORP) 20 January 2016 (2016-01-20) the whole document	1-14

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Information on patent family members

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