

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

(19) World Intellectual Property

Organization

International Bureau

(43) International Publication Date

02 February 2023 (02.02.2023)



(10) International Publication Number

WO 2023/006732 A1

(51) International Patent Classification:

C21D 8/04 (2006.01) C22C 38/06 (2006.01)
C23C 2/06 (2006.01) C22C 38/12 (2006.01)
C22C 38/00 (2006.01) C22C 38/14 (2006.01)
C21D 9/48 (2006.01) C23C 2/02 (2006.01)
C22C 38/02 (2006.01) C23C 2/20 (2006.01)
C22C 38/04 (2006.01)

GM, KE, LR, LS, MW, MZ, NA, RW, 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, 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).

(21) International Application Number:

PCT/EP2022/070919

Published:

— with international search report (Art. 21(3))

(22) International Filing Date:

26 July 2022 (26.07.2022)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

21188285.7 28 July 2021 (28.07.2021) EP

(71) Applicant: TATA STEEL IJMUIDEN B.V. [NL/NL];
Wenckebachstraat 1, 1951 JZ Velsen-Noord (NL).

(72) Inventors: AN, Yuguo; c/o Tata Steel Nederland Technology B.V., Group Intellectual Property Services - (3G.37 - 3rd floor), 1970 CA IJmuiden (NL). VAN VELDHUIZEN, Hendrik, Bart; c/o Tata Steel Nederland Technology B.V., Group Intellectual Property Services - (3G.37 - 3rd floor), 1970 CA IJmuiden (NL). TOOSE, Edgar, Matthijs; c/o Tata Steel Nederland Technology B.V., Group Intellectual Property Services - (3G.37 - 3rd floor), 1970 CA IJmuiden (NL).

(74) Agent: GROUP INTELLECTUAL PROPERTY SERVICES; Tata Steel Nederland Technology B.V., 1970 CA IJMUIDEN (NL).

(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, ME, MG, MK, MN, 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, GH,

(54) Title: HOT ROLLED STEEL SHEET AND A METHOD OF MANUFACTURING IT

(57) Abstract: Steel sheet in hot rolled condition wherein the steel has a composition in millipercents or where so indicated in ppm: C: 1-50 ppm; Mn: max. 200; Si: max. 100; Al: 10-200; Ti: 46-100; Nb: max. 100; V: max. 100; P: max. 20; S: max. 20; N: max. 100 ppm; wherein $\Sigma(Ti+Nb+V)$ together max. 200; and optionally: Cr: max. 100; Ni: max. 100; B: max. 5 ppm; Ca: max. 10; Cu: max. 100; Mo: max. 100; Sn: max. 50; the remainder being Fe and unavoidable impurities wherein the hot rolling conditions are fine-tuned for attaining a SEP 1941 waviness value Wsa in the steel surface of a finished formed article made from a blank made from the sheet, of 0.30 μm or less.



WO 2023/006732 A1

HOT ROLLED STEEL SHEET AND A METHOD OF MANUFACTURING IT

Field of the invention

The present invention relates to a hot rolled steel sheet. In a further aspect the present invention
5 relates to a method of manufacturing a hot rolled steel sheet.

Background of the invention

The property of a steel sheet that needs to be there in places in the bodywork with and without deformation, can be expressed by a waviness parameter. Steel sheets or strips that are highly formable and that show low waviness after forming into an end shape product are required in the automobile
10 industry. Typically they are suitable for the manufacture of automotive body components such as automotive outer panels. Owing to their high formability, interstitial free steel grades can be the steel grades used for such automotive outer panels. Moreover, improvements in paint baking cycles of vehicles have become important in the automobile industry. This enables realising sublime paint appearance, a global improvement of the environment and a reduction of process cost for the paint
15 baking cycle. With respect to realising sublime paint appearance, one of the issues that plays a role is the desired reduction of the thickness of the paint layers whilst keeping or improving the good paint appearance. This can be achieved if the surface of the steel sheet underneath the paint is of excellent surface quality. Thus, there is a need in the automobile industry to develop steel sheets that not only have good surface properties such as low waviness after forming but also have excellent formability.

20 It is remarked that the terms sheet and strip for a large part can be used interchangeably; in this specification sheet is defined as a part or former part of a strip.

Objectives of the invention

It is an object of the present invention to provide steel sheets that are having a good formability.

It is also an object of the invention to provide steel sheets having good surface properties such
25 as a low waviness after forming.

It is another object of the invention to provide a potentially metal coated, e.g. galvanised, steel sheet which enables realising full finish quality steel products having a low waviness for good appearance.

It is another object of the invention to enable the manufacture of automotive outer panels that
30 show little variance in the waviness due to different grades of deformation at different locations in the panels.

Description of the invention

The state of the art focuses on improving the metal coating process, such as the hot dip coating process, and on skin pass rolling. It is the aim of the present invention to improve the hot rolled steel
35 sheet such that after further processing, such as cold rolling, annealing and galvanizing, the outer surface of a resulting sheet, blank or panel has an optimal surface.

The present invention seeks to provide a reliable solution to improve the formability and to have good surface properties such as a low waviness after forming and low variance of the waviness due to forming of a final product such as an automotive body panel.

In this specification if millipercents or ppm is used, these mean millipercents by weight and ppm by weight respectively.

In a first aspect of the present invention, the steel sheet is in hot rolled condition and the steel has a composition in millipercents or where so indicated in ppm:

C: 1-50 ppm;

Mn: max. 200;

Si: max. 100;

Al: 10-200;

Ti: 46-100;

Nb: max. 100;

V: max. 100;

P: max. 20;

S: max. 20;

N: max. 100 ppm;

wherein $\Sigma(\text{Ti}+\text{Nb}+\text{V})$ together max. 200;

and optionally:

Cr: max. 100;

Ni: max. 100;

B: max. 5 ppm;

Ca: max. 10;

Cu: max. 100;

Mo: max. 100;

Sn: max. 50;

the remainder being Fe and unavoidable impurities;

characterised in that the composition and the hot rolling conditions are fine-tuned in such a way that:

$$HRT = 0.752 - 0.351 P + 0.004 G + 0.026 T < 0.10 \text{ (Equation A)}$$

wherein HRT is a parameter related to the microstructure, texture and final thickness of the steel in its hot rolled condition;

wherein P is the total volume fraction of the texture components (112)<110> and (554)<225>, determined using Electron Back-Scatter Diffraction, EBSD, on a sample representing a cross section from the sheet parallel to the rolling direction with a length of at least 1.5 mm through thickness, whereupon the texture coefficients determined by EBSD are used to calculate the said volume fraction; and wherein G is the average grain size of the steel in hot rolled condition in μm based on the scanned area in EBSD; and wherein T is the final thickness of the steel sheet in hot rolled condition in mm, in order to enable attaining a SEP 1941 waviness value Wsa in the final formed product made from the cold rolled, annealed and optionally metal coated hot rolled steel sheet, of 0.32 μm or less, preferably 0.29 μm or less, more preferably of 0.28 μm to enable attaining a delta waviness of 0.1 μm or less, preferably 0.08 μm or less, more preferably 0.06 μm or less, wherein delta waviness is defined as the Wsa cup minus the Wsa flat wherein Wsa cup

is the waviness value of a cup made from the cold rolled, annealed and optionally metal coated hot rolled steel sheet by equi-biaxial deformation of 4.5% with a Marciniak tool and W_{sa} flat is the waviness value of the cold rolled, annealed and optionally metal coated hot rolled steel sheet, wherein the finishing temperature is higher than Ar_3 transformation temperature, wherein (112) and (554) are related to the normal direction, and wherein $\langle 110 \rangle$ and $\langle 225 \rangle$ are related to the rolling direction of the hot rolled steel sheet.

P is the total volume fraction of the texture components (112) $\langle 110 \rangle$ and (554) $\langle 225 \rangle$. Here $\langle 110 \rangle$ and $\langle 225 \rangle$ are the directions that are related to the rolling direction. The (112) and (554) are related to the normal direction. The volume fraction of P is the sum of volume fraction of two orientations; (112) $\langle 110 \rangle$ and (554) $\langle 225 \rangle$. The volume fraction of each component is expressed dimensionless. In the calculation of volume fraction, an angular spread of 11 degrees is used. Due to the thickness gradient of the microstructure and the texture, the volume fraction measured at different thickness positions may be different. All the measurements that are carried out here are over the whole thickness. The texture is determined using Electron Back-Scatter Diffraction, EBSD, on a sample representing a cross section from the sheet parallel to the rolling direction with a length of at least 1.5 mm through thickness, where upon the texture coefficients determined by EBSD are used to calculate the said volume fraction; and the average grain size of the steel in hot rolled condition in μm based on the scanned area in EBSD. An intermediate stage after hot rolling is cold rolling and skin passing, where the surface properties after final cold rolling and after skin passing are important to achieve the desired waviness. During the cold rolling part the steel is cold rolled wherein the roughness R_a as measured with a cut-off threshold of 2.5 mm, herein abbreviated to $R_{a2.5}$, of the work roll of the last stand of the cold rolling mill is lower than 4.5 μm but higher than 0.6 μm . The skin-pass operation may be carried out using an electric discharge textured work roll (EDT) for which the work surfaces have a roughness $R_{a2.5}$ comprised between 2.0 μm and 3.5 μm , preferably between 1.8 μm to 3.5 μm , more preferably between 1.8 μm to 2.5 μm . The elongation of the metal sheet during the skin-pass operation is comprised between 0.5% and 2%.

In the present invention, one of the objectives is to enable production of a strip, sheet or blank that in the cold rolled and annealed condition or in the cold rolled, annealed and metal coated condition has a low waviness value expressed as W_{sa} (1-5) according to standard SEP 1941: 2012, 'Measurement of the waviness characteristic value W_{sa} (1-5) on cold rolled metallic flat products', designated hereinafter by the abbreviation W_{sa} . A low waviness W_{sa} of such a strip, sheet or blank allows reduction of the thickness of the paint layer used for attaining a given quality of paint appearance or, for a certain thickness of the paint layer, an improvement in the quality of the paint appearance. It is remarked that in SEP 1941 it is stated that the description is valid for non-deformed sheet metal in connection with changes in the waviness parameters due to forming operations. In an aspect of the present invention it is this change in the waviness that is defined herein as delta waviness that is sought to be minimised. It was found that if the features of the invention as claimed above are observed, an optimal steel sheet in hot rolled condition is realised, that can be advantageously used to manufacture cold rolled, optionally metal coated, steel sheet e.g. for the manufacture of automotive body parts. W_{sa} in the final formed product is then 0.30 μm or less, preferably 0.29 μm or less, more preferably of 0.28 μm or less and/or delta waviness is then 0.1 μm or less, preferably 0.08 μm or less, more preferably

0.06 μm or less. For a given thickness T, a suitable P or G has to be chosen to comply with Equation A (herein also referred to as Eqn (A)).

In a second embodiment of the invention, in the steel sheet at least one of the following elements in the steel is present in the mentioned ranges given in millipercents or where so indicated in ppm:

- 5 - C: 1-30 ppm;
- Mn: 10-200, preferably 40-180;
- Si: 1-50, preferably 2-15;
- Al: 10-100;
- Ti: 46-95, preferably 46-90;
- 10 - Nb: max. 90, more preferably max. 10;
- V: max. 90, preferably max. 50, more preferably max. 10;
- P: max. 15;
- S: max. 15;
- N: max. 80, preferably max. 60 ppm;
- 15 - wherein $\Sigma(\text{Ti}+\text{Nb}+\text{V})$ together max. 100, preferably max. 90;
- and optionally:
 - Cr: max. 60;
 - Ni: max. 60;
 - B: max. 4 ppm;
 - 20 - Ca: max. 5;
 - Cu: max. 60;
 - Mo: max. 60;
 - Sn: max. 30.

In one embodiment of the invention, the value of $\Sigma(\text{Ti}+\text{Nb}+\text{V})$ together is max. 100 or preferably
25 max. 90. The advantage of having such a value is to avoid any clogging during continuous casting.

In an alternative embodiment of the invention, in the steel sheet at least one of the elements in the steel is present in the mentioned ranges given in millipercents or where so indicated in ppm:

- C: 1-22 ppm;
- Mn: 10-150;
- 30 - Si: 1-13;
- Al: 20-80;
- Ti: 46-70;
- P: 1-13;
- S: 1-13;
- 35 - N: 10-60 ppm;
- and optionally:
 - Nb: max. 3;
 - V: max. 5;
 - Cr: max. 50;
 - 40 - Ni: max. 50;

- B: max. 3 ppm;
- Ca: max. 2;
- Cu: max. 50;
- Mo: max. 40;
- Sn: max. 20.

In another embodiment of the invention, in the steel sheet at least one of the following elements in the steel is present in the mentioned ranges given in millipercents or where so indicated in ppm:

- C: 1-21 ppm;
- Mn: 40-130;
- Si: 2-13;
- Al: 30-70;
- Ti: 50-70;
- P: 2-13, preferably 1-5;
- S: 3-13;
- N: 10-40 ppm;

and optionally:

- Nb: max. 2;
- V: max. 4;
- Cr: max. 40;
- Ni: max. 40;
- B: max. 2 ppm;
- Ca: max. 1;
- Cu: max. 40;
- Mo: max. 20;
- Sn: max. 10.

The present invention in a further aspect relates to a steel sheet, which is characterised in that

$$- \quad HRT = 0.752 - 0.351 P + 0.004 G + 0.026 T < 0.09.$$

If the HRT value is lower, the waviness value and/or the delta waviness value of the resulting product is also lower. A further embodiment of the present invention relates to a steel sheet where the G is 22 µm or smaller, preferably 20 µm or smaller. If the value of G is lower, then the value of HRT is lower. It allows to achieve a fine grain size, which is favourable for the final product.

A further aspect of the present invention relates to a method for manufacturing a steel sheet as described above for each of the compositions described. The manufacturing method to produce a product from the hot rolled steel sheet according to the present invention embodiments may after the hot rolling step comprise steps such as a pickling step, a cold rolling step, an annealing step, a galvanising step, and a temper rolling or skin pass step. The steel with the specified composition according to the embodiments of the present invention is smelted, for example, in a converter and formed into a slab by a continuous casting process or the like.

The slab to be used is preferably produced by a continuous casting process to prevent macro-segregation of the components. The slab to be used may be produced by an ingot-making method or a

thin slab casting process. Alternatively, after a slab is produced, in addition to a conventional method in which a slab is first cooled to a room temperature and then heated again, an energy saving process, such as hot direct rolling or direct rolling, may be applied. The energy saving process may comprise placing a slab into a heating furnace whilst keeping the slab temperature without cooling to a room temperature, or performing rolling immediately after keeping the temperature for a short time.

The slab used in the hot rolling step may be heated. In heating, the slab heating temperature is preferably as low as possible for the aim of energy saving. If however the heating temperature falls below 1150°C, the carbide is not sufficiently dissolved. In terms of an increase in the scale loss with increasing oxidation weight gains, the slab heating temperature is desirably 1250°C or lower.

In hot rolling, the slab is rolled at a hot rolling finishing temperature that is at or higher than the Ar3 transformation temperature, then cooled at an average cooling rate of 30°C/s or higher, and then coiled. Here, the Ar3 temperature is the temperature at which ferrite transformation starts in the cooling. If the hot rolling finishing temperature falls below the Ar3 temperature, both α and γ phase are generated in the rolling, and as a result, the grain size of ferrite becomes large and the grains will be less uniform through the thickness. Therefore, the hot rolling finishing temperature is the Ar3 temperature or higher.

As a maximum hot rolling finishing temperature 970°C is preferred. In one embodiment of the invention, the method comprises a step of hot rolling the steel sheet; wherein the hot rolling finishing temperature is lower than 960°C. Thus, the method comprises a step of hot rolling the steel sheet; wherein the hot rolling finishing temperature is lower than 960°C, wherein the finishing temperature is higher than Ar3 transformation temperature. The maximum value of hot rolling finishing temperature is preferably Ar3+70°C. A further embodiment of the present invention relates to the method for manufacturing a steel sheet as described above, wherein the hot rolling finishing temperature is lower than 945°C.

Due to temperature gradient through thickness of hot rolled sheet in the final hot rolling step, it is recommended that if the gauge thickness of hot rolled sheet is thicker, the preferred hot rolling finishing temperature is lower. For example, for a thickness gauge of 3.5 mm, a finishing temperature of Ar3+50°C is chosen, while for thickness gauge of 4.7 mm, a finishing temperature of Ar3+30°C is preferred.

A further embodiment of the present invention relates to a method for manufacturing a steel sheet as described above, wherein reduction in the last stand of the hot rolling finishing mill is more than 15%, preferably more than 20%. By an increased reduction, the grain size G is finer and the texture component P is increased.

In a further embodiment, the present invention relates to the method for manufacturing a steel sheet as described above, wherein the steel sheet is cold rolled and wherein the roughness Ra measured with a cut-off threshold at 2.5 mm, herein abbreviated to Ra2.5, of the work roll of the last stand of the cold rolling mill is lower than 4.5 μ m but higher than 0.6 μ m.

During cold rolling, a total cold rolling reduction is generally comprised between 50% and 85%, so as to obtain a substrate with a thickness which is for example comprised between 0.2 and 2 mm. In some embodiments, an annealing step may be performed. The cold rolled substrate is then subjected to annealing conducted in a conventional way in an annealing furnace under a reducing atmosphere, with a view to recrystallization after the work hardening which it has undergone during the cold rolling

operations. The annealing step is a step of heating the cold rolled steel sheet to a temperature of 650°C to 900°C. The annealing step may be performed preferably in a range of 780°C - 820°C. After recrystallization annealing, the steel sheet is cooled down to a temperature close to the bath temperature. After entry in the bath, the steel sheet or the substrate is metal coated on its two sides with a Zn based coating. The coating weight per surface can be 35 to 45 g/m². Then the metal sheet is subjected to wiping by means of nozzles, which project a wiping gas, placed on either side of the metal sheet. The wiping gas is ejected from each nozzle along a direction horizontal and orthogonal to the metal sheet. The running speed of the substrate in the production line and therefore in front of the nozzle is between 80 m/min and 160 m/min. This can be preferably greater than 100 m/min, or even 120 m/min.

The outlet of the nozzle is generally positioned at a distance 6 mm to 12 mm from the metal sheet along the main ejection direction. The outlet generally appears as a rectangular slot which extends, perpendicularly to the running direction of steel sheet substrate and over a width at least equal to the width of the metal sheet. The distance of the nozzle outlet to the metal sheet is preferably not greater than 10 mm and more preferably below 8 mm.

When the metal coated steel sheet is completely cooled, the metal sheet may undergo a temper rolling or tension levelling operation for giving texture to the outer surfaces of the metal coating. The transferred surface texture to the outer surfaces of the metal coating with sufficient roughness enables the metal sheet to retain sufficient amount of oil applied on the metal sheet, in order for its forming process to be properly carried out. The other purpose of this transferred surface texture is that it provides the metal sheet with desired low waviness properties.

The skin pass operation may be carried out using an electric discharge textured work roll (EDT) for which the work surfaces have a roughness Ra2.5 comprised between 2.0 µm and 3.5 µm, preferably between 1.8 µm to 3.5 µm; more preferably between 1.8 µm to 2.5 µm. The elongation of the metal sheet during the skin pass operation is comprised between 0.5% and 2%. All steel sheets are given a waviness Wsa of less than 0.35 µm and preferably less than 0.30 µm. The steel sheet optionally having been temper rolled or skin passed may then be cut out and undergoes a forming process, for example by stretching, drawing or bending, in order to form a part which may then be painted on each coating. After the deformation process, the outer surfaces of the metal coating of the part have a waviness Wsa value of less than or equal to 0.32 µm, or even less than or equal to 0.30 µm, or even less than or equal to 0.28 µm. This waviness may for example be measured after equi-biaxial deformation of 4.5% in the rolling direction and the transverse direction on the sheet plane, or approximately 9% through thickness direction.

In a further embodiment the present invention relates to a method for manufacturing a steel sheet as described above, wherein the steel is hot dip galvanised and temper rolled and wherein the roughness Ra2.5 of the work roll of the last stand of the temper rolling mill is in a range of 1.0 µm-5.0 µm. In a further aspect, the present invention relates to a steel sheet wherein the hot rolled sheet gauges are of thickness between 3 mm to 5 mm.

Examples

The invention will now be further explained by means of the following, non-limiting examples. Steels having a chemical composition shown in Table 1 and the balance being Fe and unavoidable impurities were smelted in a vacuum melting furnace and slab material having a thickness of 225 mm was obtained.

Table 1: steel compositions all in milli percent except C and N in ppm. The I.E. represents invention examples and C.E. represents comparative examples. The underlined numbers are out of the scope of the present invention.

Sample	C	N	Mn	P	S	Si	Al	Ti	V	Mo	Cu	Cr	Sn	Ni	Inv.
1	13	23	129	10	6	4	51	69	3	2	9	18	3	14	I.E.
2	13	22	105	8	6	3	53	68	2	2	10	18	3	15	I.E.
3	13	23	129	10	6	4	51	69	3	2	9	18	3	14	I.E.
4	12	20	95	5	6	4	42	<u>42</u>	2	2	9	16	3	15	C.E.
5	9	21	93	5	6	3	59	<u>45</u>	1	5	17	25	3	14	C.E.
6	16	31	110	6	6	3	52	<u>44</u>	2	5	21	22	6	28	C.E.
7	15	18	82	5	6	2	53	69	2	2	10	15	3	14	I.E.
8	13	23	129	10	6	4	51	69	3	2	9	18	3	14	I.E.
9	13	22	105	8	6	3	53	68	2	2	10	18	3	15	I.E.
10	13	23	129	10	6	4	51	69	3	2	9	18	3	14	I.E.
11	13	23	102	7	6	3	56	70	2	2	9	19	3	14	I.E.
12	13	23	102	7	6	3	56	70	2	2	9	19	3	14	I.E.
13	15	20	111	7	7	3	52	69	2	4	10	19	3	14	I.E.
14	11	21	50	5	7	4	45	68	1	4	12	11	6	19	I.E.
15	11	21	50	5	7	4	45	68	1	4	12	11	6	19	I.E.

In the examples the slab thickness is approximately 225 mm, the transfer gauge is in the range of 35 mm to 40 mm, and the final gauge thicknesses of the hot rolled strips is in the range of 3 mm to 5 mm. The average target cooling rate after the finish rolling is at least 30°C/s, so that the microstructure of the hot rolled steel sheet becomes a more uniform microstructure. The coiling temperature is 750°C or lower, but higher than 550°C. Thus the microstructure of the hot rolled steel sheet becomes a more uniform microstructure and the scale loss due to oxidation is reduced.

In all of the experiments, a pickling step is performed. The pickling step is a step of removing an oxide scale of a surface of a hot rolled steel sheet obtained in the hot rolling step by performing pickling. The cold rolling step is a step of cold rolling a pickled sheet after the pickling step. In some experiments, at least the last cold rolling pass is carried out with relatively smooth work rolls. In such a case, the surfaces of the rectified and non-etched rolls of the rolling mill directly in contact with the above mentioned sheet for ensuring its deformation, have a roughness Ra2.5 less than 0.5 μm . The aim for the waviness Wsa (1-5) of the cold rolled sheet is less than 0.40 μm . In the examples listed below, all steel sheets are cold rolled with such a surface characteristic. In the examples listed below, the roughness Ra2.5 of the work surfaces of the EDT work rolls for temper rolling is comprised between 2.50 μm and 3.0 μm . The elongation during the temper rolling operation is in the range of 1.0%-1.5%. The hot rolling was performed with the process conditions shown in Table 2. The rest of process; pickling, cold rolling, annealing, galvanising and temper rolling were conducted as described in the previous section. The waviness after temper rolling, and thereafter biaxial stretching using a Marciniak tool at a strain of 4.5% are also shown in Table 2. From example 7 to example 15, Ra2.5, CR (surface roughness of the work roll used for cold rolling CR in the last stand of the cold rolling mill) is 0.5 μm and Ra2.5, TR (surface roughness of the work roll used for temper rolling TR of the temper rolling mill) is 2.8 μm .

Table 2.

sample	Slab mm	Hot rolled T (mm)	Temp furnace °C	P in %	G in µm	Finishing Temp °C	Coiling Temp °C	Cooling rate °C/s	Wsa flat	Wsa cup	delta waviness	Invention	Eqn (A)	Remark
1	225	4.17	1200			936	700	69	0.223	0.290	0.067	I.E.	-	-
2	225	4.16	1194			949	748	67	0.221	0.310	0.089	I.E.	-	-
3	225	4.16	1205			946	620	42	0.227	0.319	0.092	I.E.	-	-
4	225	4.16	1213			917	612	41	0.211	0.451	0.24	C.E.	-	-
5	225	4.16	1207			955	574	66	0.226	0.409	0.183	C.E.	-	-
6	225	4.16	1208			940	641	97	0.203	0.395	0.192	C.E.	-	-
7	225	4.69	1209	2.41	23.1	956	679	61	0.216	0.329	0.113	C.E.	no	B
8	225	4.69	1201	2.53	16.0	921	678	61	0.214	0.271	0.057	I.E.	yes	E
9	225	3.52	1193	2.52	16.9	928	678	67	0.211	0.247	0.036	I.E.	yes	E
10	225	4.68	1209	2.43	18.0	921	681	55	0.205	0.273	0.068	I.E.	yes	E
11	225	3.52	1208	2.44	19.9	950	681	68	0.223	0.291	0.068	I.E.	yes	G
12	225	3.52	1213	2.42	22.3	953	678	71	0.219	0.294	0.075	I.E.	yes	G
13	225	3.52	1212	2.46	20.2	943	678	75	0.211	0.273	0.062	I.E.	yes	G
14	225	4.74	1223	2.32	22.4	943	684	75	0.219	0.371	0.152	C.E.	no	B
15	225	4.74	1213	2.39	22.9	940	622	62	0.202	0.346	0.144	C.E.	no	B

Dependent on whether the microstructure and texture satisfy the HRT criterion as defined according to the present invention, the waviness W_{sa} after biaxial stretching turns out to be lower or higher, which leads to a bad (B), good (G) or excellent (E) surface appearance as can be seen in Table 2. The waviness values W_{sa} of the steel sheet surfaces are measured after the skin pass operation (flat) and after stretching (cup). The latter is carried out by equi-biaxial deformation of 4.5% with a Marciniak tool. The results of the measurements of W_{sa} are grouped in table 2. The use of parameter HRT satisfying Equation A gives the possibility of attaining a waviness W_{sa} after a skin pass and equi-biaxial deformation as described above of smaller than or equal to $0.30\text{ }\mu\text{m}$. When the hot band microstructure and texture do not satisfy the HRT criterion, the waviness becomes considerably higher, as can be seen in Table 2. For higher values of hot rolled T, a lower value of finishing temperature can be selected. For samples 7,14,15, the hot rolled T has a higher value. In such cases it may be possible to lower the finishing temperatures to a lower value to comply with Eqn (A). Even though for sample 8, the hot rolled T has a higher value (4.69 mm), a lower the finishing temperature such as 921°C is chosen so that it complies with Eqn (A). The waviness W_{sa} as mentioned herein is as defined in standard SEP 1941: 2012. The present invention has been described above with reference to several exemplary embodiments. Modifications and alternative implementations of some parts or elements are possible, and are included in the scope of protection as defined in the appended claims.

Claims

1. Steel sheet in hot rolled condition wherein the steel has a composition in millipercents or where so indicated in ppm:

- C: 1-50 ppm ;
- Mn: max. 200;
- Si: max. 100;
- Al: 10-200;
- Ti: 46-100;
- Nb: max. 100;
- V: max. 100;
- P: max. 20;
- S: max. 20;
- N: max. 100 ppm;
- wherein $\Sigma(\text{Ti}+\text{Nb}+\text{V})$ together max. 200;
- and optionally:
- Cr: max. 100;
- Ni: max. 100;
- B: max. 5 ppm;
- Ca: max. 10;
- Cu: max. 100;
- Mo: max. 100;
- Sn: max. 50;
- the remainder being Fe and unavoidable impurities

characterised in that the composition and the hot rolling conditions are fine-tuned in such a way that:

$$- \quad HRT = 0.752 - 0.351 P + 0.004 G + 0.026 T < 0.10$$

wherein HRT is a parameter related to the microstructure, texture and final thickness of the steel in its hot rolled condition;

wherein P is the total volume fraction of the texture components (112)<110> and (554)<225>, determined using Electron Back-Scatter Diffraction, EBSD, on a sample representing a cross section from the sheet parallel to the rolling direction with a length of at least 1.5 mm through thickness, whereupon the texture coefficients determined by EBSD are used to calculate the said volume fraction; and wherein G is the average grain size of the steel in hot rolled condition in μm based on the scanned area in EBSD; and wherein T is the final thickness of the steel sheet in hot rolled condition in mm, in order to enable attaining a SEP 1941 waviness value, Wsa, in the final formed product made from the cold rolled, annealed and optionally metal coated hot rolled steel sheet, of 0.32 μm or less, preferably 0.29 μm or less, more preferably of 0.28 μm , to enable attaining a delta waviness of 0.1 μm or less, preferably 0.08 μm or less, more preferably 0.06 μm or less, wherein delta waviness is defined as the Wsa cup minus the Wsa flat wherein Wsa cup is the

waviness value of a cup made from the cold rolled, annealed and optionally metal coated hot rolled steel sheet by equi-biaxial deformation of 4.5% with a Marciniak tool and Wsa flat is the waviness value of the cold rolled, annealed and optionally metal coated hot rolled steel sheet;

wherein the finishing temperature is higher than Ar3 transformation temperature, wherein (112) and (554) are related to the normal direction, and wherein <110> and <225> are related to the rolling direction of the hot rolled steel sheet.

2. Steel sheet according to claim 1 wherein at least one of the following elements in the steel is present in the mentioned ranges given in millipercents or where so indicated in ppm:

- C: 1-30 ppm;
- Mn: 10-200, preferably 40-180;
- Si: 1-50, preferably 2-15;
- Al: 10-100;
- Ti: 46-95, preferably 46-90;
- Nb: max. 90, more preferably max. 10;
- V: max. 90, preferably max. 50, more preferably max. 10;
- P: max. 15;
- S: max. 15;
- N: max. 80, preferably max. 60 ppm;
- wherein $\Sigma(\text{Ti}+\text{Nb}+\text{V})$ together max. 100, preferably max. 90;

and optionally:

- Cr: max. 60;
- Ni: max. 60;
- B: max. 4 ppm;
- Ca: max. 5;
- Cu: max. 60;
- Mo: max. 60;
- Sn: max. 30.

3. Steel sheet according to claim 1 or claim 2 wherein at least one of the following elements in the steel is present in the mentioned ranges given in millipercents or where so indicated in ppm:

- C: 1-22 ppm;
- Mn: 10-150;
- Si: 1-13;
- Al: 20-80;
- Ti: 46-70;
- P: 1-13;
- S: 1-13;
- N: 10-60 ppm;

and optionally:

- Nb: max. 3;
 - V: max. 5;
 - Cr: max. 50;
 - Ni: max. 50;
 - B: max. 3 ppm;
 - Ca: max. 2;
 - Cu: max. 50;
 - Mo: max. 40;
 - Sn: max. 20.
4. Steel sheet according to any one of claims 1 to 3 wherein at least one of the following elements in the steel is present in the mentioned ranges given in millipercen or where so indicated in ppm:
- C: 1-21 ppm;
 - Mn: 40-130;
 - Si: 2-13;
 - Al: 30-70;
 - Ti: 50-70;
 - P: 2-13, preferably 1-5;
 - S: 3-13;
 - N: 10-40 ppm;
- and optionally:
- Nb: max. 2;
 - V: max. 4;
 - Cr: max. 40;
 - Ni: max. 40;
 - B: max. 2 ppm;
 - Ca: max. 1;
 - Cu: max. 40;
 - Mo: max. 20;
 - Sn: max. 10.
5. Steel sheet according to any one of the preceding claims characterised in that
- $HRT = 0.752 - 0.351 P + 0.004 G + 0.026 T < 0.09$.
6. Steel sheet according to any one of the preceding claims wherein G is 22 µm or smaller, preferably 20 µm or smaller.
7. A method for manufacturing a steel sheet according to claims 1 to 6, wherein the method comprises a step of hot rolling the steel sheet; wherein the hot rolling finishing temperature is lower than 960°C, wherein the finishing temperature is higher than Ar3 transformation temperature.

8. The method for manufacturing a steel sheet according to claim 7, wherein the hot rolling finishing temperature is lower than 945°C.
9. The method for manufacturing a steel sheet according to any of the claims 7 to 8, wherein the reduction in the last stand of the hot rolling finishing mill is more than 15%, preferably more than 20%.
10. The method for manufacturing a steel sheet according to any of the claims 7 to 9, wherein the steel sheet is cold rolled and, wherein the roughness Ra2.5 of the work roll of the last stand of the cold rolling mill is lower than 4.5 µm.
11. The method for manufacturing a steel sheet according to any of the claims 7 to 9, wherein the steel sheet is hot dip galvanised and temper rolled and wherein the roughness Ra2.5 of the work roll of the last stand of the temper rolling mill is in a range of 1.0 µm-5.0 µm.
12. Steel sheet according to claims 1 to 6 wherein the hot rolled sheet gauges are of a thickness between 3 and 5 mm.

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2022/070919

A. CLASSIFICATION OF SUBJECT MATTER INV. C21D8/04 C23C2/06 C22C38/00 C21D9/48 C22C38/02 C22C38/04 C22C38/06 C22C38/12 C22C38/14 C23C2/02 C23C2/20		
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) C21D C23C C22C		
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, INSPEC, CHEM ABS Data, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	ELOOT KAREL ET AL: "Recrystallization and Related Phenomena. Texture Evolution during Cold Rolling and Recrystallisation of IF Steel with a Strong {111} Hot Band Texture.", ISIJ INTERNATIONAL, vol. 38, no. 6, 1 January 1998 (1998-01-01), pages 602-609, XP055878728, JP ISSN: 0915-1559, DOI: 10.2355/isijinternational.38.602	1-6,12
A	"2. Experimental", "3.1. Hot band and Cold rolled conditions", Figs. 1,2 ----- -/--	7-11
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "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 25 October 2022		Date of mailing of the international search report 04/11/2022
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Abrasonis, Gintautas

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2022/070919

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KEI SAKATA, SAIJI MATSUOKA, TAKASHI OBARA, KOZO TSUNOYAMA, MASAJI SHIRAISHI: "Formable Cold Rolled Sheet Steel with Ultra-High Lankford Value by Lubricant Hot Rolling in Ferrite Region", MATERIA JAPAN, vol. 36, no. 4, 20 April 1997 (1997-04-20) , pages 376-378, XP009532680, ISSN: 1340-2625, DOI: 10.2320/materia.36.376 Fig. 2, 3 -----	1-11
X	RUIZ-APARICIO L J ET AL: "Development of {111} transformation texture in interstitial-free steels", METALLURGICAL AND MATERIALS TRANSACTIONS A, SPRINGER-VERLAG, NEW YORK, vol. 32, no. 9, 1 September 2001 (2001-09-01), pages 2325-2334, XP019693713, ISSN: 1543-1940 -----	1, 2, 5, 7-12
A	Tables I-III, sections "Experimental Procedure", "III. Results"; Figs. 4, 6 -----	3, 4
A	US 2020/087761 A1 (AARNTS MAXIM PETER [NL] ET AL) 19 March 2020 (2020-03-19) the whole document -----	1-11
A	US 2020/332379 A1 (FRIEDEL FRANK [DE] ET AL) 22 October 2020 (2020-10-22) the whole document -----	1-11
A	CN 112 538 593 A (TKAS AUTO STEEL COMPANY LTD) 23 March 2021 (2021-03-23) the whole document -----	1-11
A	US 2003/196735 A1 (SUGIURA NATSUKO [JP] ET AL) 23 October 2003 (2003-10-23) the whole document -----	1-11
A	BUTRON-GUILLEN, MARTHA PATRICIA; JONAS, JOHN J.: "Effect of finishing temperature on hot band textures in an IF steel", ISIJ INTERNATIONAL, vol. 36, no. 1, 1 January 1996 (1996-01-01), pages 68-73, XP009532688, ISSN: 0915-1559, DOI: 10.2355/isijinternational.36.68 the whole document ----- -/--	1-11

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2022/070919

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CHENG, XIAOJUN; JIA, YOUSHENG; LI, ZHICHAO; PENG, WEI; ZHOU, CHUNQUAN C: "Effects of coiling temperature on microstructure and mechanical properties of interstitial free (Ti- IF) steel sheet", JINSHU RECHULI - HEAT TREATMENT OF METALS, vol. 37, no. 6, 1 January 2012 (2012-01-01), pages 85-88, XP009532704, ISSN: 0254-6051 the whole document -----	1-11

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2022/070919

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2020087761 A1	19-03-2020	BR 112019007262 A2 CA 3039083 A1 CN 109844158 A DE 202017007170 U1 EP 3526359 A1 JP 7066698 B2 JP 2019534949 A KR 20190070336 A US 2020087761 A1 US 2022064765 A1 WO 2018073117 A1	09-07-2019 26-04-2018 04-06-2019 15-11-2019 21-08-2019 13-05-2022 05-12-2019 20-06-2019 19-03-2020 03-03-2022 26-04-2018
US 2020332379 A1	22-10-2020	BR 112019002875 A2 CA 3033685 A1 CN 109715838 A EP 3516084 A1 EP 4071255 A1 JP 2019532172 A KR 20190055150 A US 2020332379 A1 WO 2018054742 A1	14-05-2019 29-03-2018 03-05-2019 31-07-2019 12-10-2022 07-11-2019 22-05-2019 22-10-2020 29-03-2018
CN 112538593 A	23-03-2021	NONE	
US 2003196735 A1	23-10-2003	CA 2422753 A1 CN 1462317 A EP 1327695 A1 KR 20030030032 A US 2003196735 A1 WO 0224968 A1	18-03-2003 17-12-2003 16-07-2003 16-04-2003 23-10-2003 28-03-2002