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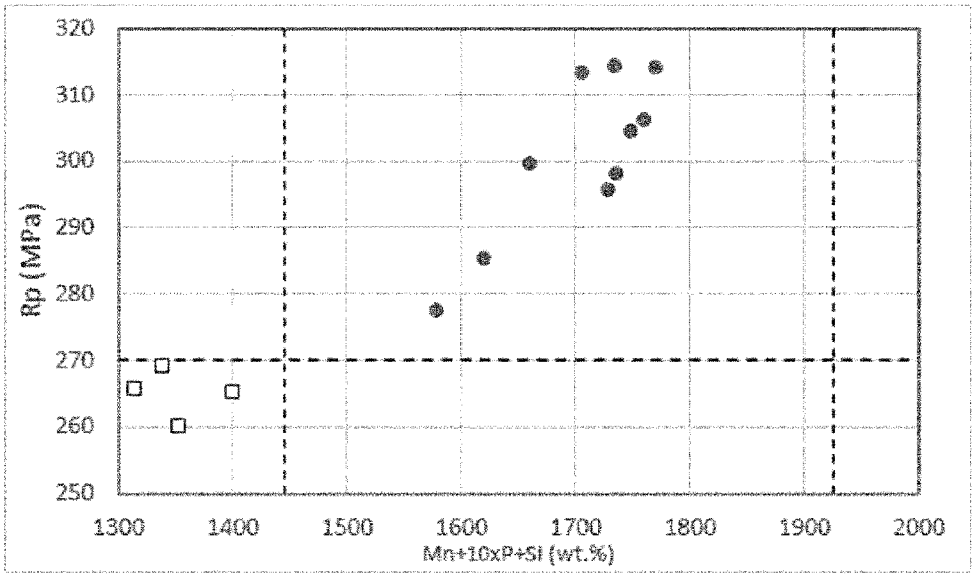


FIGURE 2

(57) Abstract: This invention relates to a cold-rolled and annealed bake-hardenable steel hot-dip galvanised or electrogalvanised strip or sheet and a method for producing the strip or sheet.

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STEEL STRIP OR SHEET AND METHOD FOR PRODUCING IT

Field of the invention

This invention relates to a cold-rolled and annealed bake-hardenable steel hot-dip galvanised strip or sheet and a method for producing the strip or sheet.

Background of the invention

An ever-increasing drive for reducing the weight of steel in applications, and in particular in transport applications, has pressed the steel industry to provide solutions for improving the mechanical properties of steel.

Various strengthening means are at the steel industries' disposal such as, but not limited to, increasing the temper rolling reduction after annealing, changing the chemical composition, changing processing conditions such as the cold-rolling reductions imposed on the strip or sheet, or the annealing conditions of the cold-rolled steel strip or sheet.

The various means affect each other and may improve some property and adversely affect another. For instance, increasing the temper rolling reduction improves the yield strength, but reduces the uniform elongation values.

Any improvement therefore requires a careful balance to be struck between improving the most important properties for certain applications whilst simultaneously sacrificing as little as possible of the less important properties.

A possible way to increase the strength without deteriorating the relevant properties is adapting the chemistry. From literature (e.g. S. Hoile in "Materials Science and Technology October 2000 Vol. 16, 1079) it is known that the strength for ultra-low carbon steels that are commonly used for bake-hardenable grades depends on the chemical composition of the alloy. Modifying the chemistry not only requires a careful balance to be struck between the properties but also between the processing parameters.

JP06-322441 discloses a method for producing a high strength cold rolled steel plate having formability and baking hardenability based on a steel composition having 0.003 to 0.010% C.

Objectives of the invention

It is an object of the invention to provide a cold-rolled and annealed bake-hardenable steel hot-dip galvanised strip or sheet which provides a yield strength of at least 270 MPa // RD.

It is also an object of the invention to provide a cold-rolled and annealed bake-hardenable steel hot-dip galvanised strip or sheet which provides a tensile strength of at least 360 MPa // RD.

It is also an object of the invention to provide a cold-rolled and annealed bake-hardenable steel hot-dip galvanised strip or sheet which provides an elongation at a gauge length of 80 mm of at least 28% // RD.

It is also an object of the invention to provide a cold-rolled and annealed bake-hardenable steel hot-dip galvanised strip or sheet which has a bake-hardening potential BH2 of at least 30 MPa // RD.

Description of the invention

One or more of the objects is reached with a cold-rolled and annealed bake-hardenable steel hot-dip galvanised strip or sheet having a chemical composition comprising, in wt.%:

C: 0.0022 to 0.0042;

Al_sol: 0.027 to 0.066;

Nb: 0.004 to 0.028;

B: 0.0004 to 0.0017;

Ti: 0.004 to 0.014;

N: 0.0004 to 0.0033;

S: 0.022 or less;

Cr: 0.045 or less;

V: 0.005 or less;

Cu: 0.045 or less;

Ni: 0.045 or less;

Mo: 0.011 or less;

Ca: 0 to 0.0100;

$1.445 \leq Mn\ (wt.\%) + 10 * P\ (wt.\%) + Si\ (wt.\%) \leq 1.925$;

wherein the silicon content is at least 0.148 and/or at most 0.248 wt.%;

the remainder being Fe and inevitable impurities,

wherein the yield strength (Rp) // RD is between 270 and 330 MPa, the tensile strength (Rm) // RD is between 360 and 460, the total strain (A80) // RD is at least 28%, the n0-value is at least 0.13, the r0 value is at least 1.10, and a bake-hardening index (BH2) of at least 30 MPa.

All chemical compositions are given in wt.% unless otherwise indicated. The steel is preferably produced on the basis of a steel melt produced in a Basic Oxygen Steelmaking (BOS) process, preferably also using vacuum degassing technology. This process is preferable over the other commonly used steelmaking process, the Electric Arc Furnace (EAF) process, because the BOS-process is able to produce steels with a low impurity level. The EAF-process is based on scrap melting whereas the BOS-process starts from virgin pig iron to which only small amounts and carefully selected scrap is added as a coolant during the refining process of the pig iron into a steel melt ready to

be cast into a thick slab (t: 150-350 mm) or a thin slab (t: 50-150 mm) in a continuous casting process, or into a strip (t < 20 mm) in a strip casting process. The cast slab or strip is the input for the hot rolling process, of which the resulting hot-rolled strip is the input for the subsequent cold-rolling process according to the invention.

The inventors found that it is important to meet the following criterion for Mn, Si and P: 1.445 ≤ (Mn (wt.%) + 10 * P (wt.%) + Si (wt.%)) ≤1.925 wt.%. A high level of Mn leads to bad control of the C level, hence to big variations in the mechanical properties, including the bake hardening response. A high level of Si can lead to undesirable oxide types which in turn will lead to coating adhesion problems. A high level of P can cause casting problems due to bulging and it can also lead to high rolling forces and high wear of the rolling cylinders. High P can also lead to welding issues. If the values are too low, then the strength requirements will not be met. Preferably (Mn (wt.%) + 10 * P (wt.%) + Si (wt.%)) is at most 1.825 and/or at least 1.525 wt.%.

The inventors have found that using a careful balance between the elements Mn, Si and P, in combination with a carefully balanced process, it is possible to produce a Ti stabilized Ultra Low Carbon steel with a minimum yield strength of 270 MPa //RD, a minimum tensile strength of 360 MPa //RD, a minimum elongation A80 of at least 28% // RD a minimum bake hardening response BH2 (according to EN10325:2002) of at least 30 MPa // RD. Despite relatively high rolling forces during cold rolling, the width of the rolled coil can be up to 2000 mm.

It is noted that the Rp, Rm, A80, n0, r0 as claimed are determined according to VDA239-100:2016, and the BH2 according to EN10325:2002. The notation // RD means that the property is measured on a tensile specimen with its longitudinal direction being parallel to the rolling direction. The 0 behind n and r denote the same (0 being the angle to the rolling direction). To prevent misunderstanding it is noted that A80 is the total elongation, measured over a gauge length of 80 mm. The BH2 was determined by measuring the increase in Rp after heating the cold-rolled, annealed and hot-dip galvanised material after a paint-baking cycle of 20 minutes at 170 °C, according to EN10325:2006. The tensile tests were performed according to EN10002-1:2001.

In an embodiment A80 // RD is at least 30% and preferably at least 32%. In an embodiment n0 is at least 0.15 and preferably at least 0.16. In an embodiment the r0-value is at least 1.20 and preferably at least 1.30. In case of r0 and n0 both parameters higher values indicate better formability.

In an embodiment BH2 // RD is at least 40 MPa, preferably at least 45 MPa. Preferably Rp // RD is at least 280 MPa, more preferably at least 290 MPa.

In the steels according to the invention titanium (Ti) is added mainly to make sure all N has precipitated as TiN. Free N is detrimental for the mechanical properties. Any excess Ti might precipitate as TiC or $Ti_4C_2S_2$.

In the steels according to the invention niobium (Nb) is added in such a way that most of the C precipitates as NbC. However, a small amount of C in solid solution is necessary to get the required BH response.

In the steels according to the invention aluminium (Al) is used as a deoxidizing agent. However, in case not all N has precipitated as TiN, Al is also added as an alloying element to promote the formation of aluminium nitride in order to improve the deep-drawing. In consequence, Al can be found in steel as aluminium oxide (remnants from the deoxidation) metallic Al and AlN. Al and AlN can both be dissolved in acid and is therefore jointly referred to as Al_sol. The total aluminium content of the steel is therefore given as Al_tot = Al_ox + Al_sol.

In an embodiment of the invention the P-content is at least 0.054 and preferably at least 0.065 wt.%. Preferably the P-content is at most 0.099 and more preferably at most 0.085 wt.%. A preferred range is therefore 0.065−0.085 wt.%.

In an embodiment the Mn-content is at least 0.610, and preferably at least 0.660 wt.%. Preferably the Mn-content is below 0.880 and more preferably below 0.800 wt.%.

In the steel according to the invention the Si-content is at least 0.148. In an embodiment the Si-content is at least 0.165 wt.%. In the steel according to the invention the Si-content is at most 0.248. In an embodiment the Si-content is at most 0.225 wt.%.

In an embodiment of the invention the S-content is at least 0.010, more preferably at most 0.005 wt.%.

In a preferable embodiment the maximum waviness Wsa(1-5) after deformation of 5% (according to SEP1941 and SEP1942) is 0.37 µm. This value is obtained in a reproducible and robust way. The value of the Wsa(1-5) depends to a significant extent on the roughness of the work roll in the last cold rolling stand of the cold-rolling mill.

In an embodiment the steel strip or sheet has a roughness value (Ra) of between 0.80 and 1.50 µm and a waviness value (Wsa(1-5)) after 5% deformation of at most 0.37 µm.

Preferably the waviness value Wsa(1-5) after 5% deformation is at most 0.35 µm, and more preferably at most 0.34 µm and/or the Ra is at most 1.45 µm.

In a further embodiment of the invention, the steel strip or sheet according to the invention is provided with a metallic coating layer after cold-rolling and annealing, such as zinc layer which can contain a small amount of Al to allow the formation of a very thin ternary alloy layer composed of approximately 45% Al, 35% Fe and 20-35% Zn ($Fe_2Al_{5-x}Zn_x$) to ensure proper adhesion of the zinc layer to the substrate. For this reason between 0.10 to 1.0 wt.% Al may be added to the zinc bath. The metallic coating layer may be a zinc alloy coating layer comprising 0.3-4.0 wt.% Mg and 0.3-6.0 wt.% Al; optionally at most 0.2 wt.% of one or more additional elements, unavoidable impurities;

the remainder being zinc. Preferably the alloying element contents in the zinc-alloy coating layer shall be 1.0 – 2.0 wt.% Magnesium and 1.0 –3.0 wt.% Aluminium, optionally at most 0.2 wt.% of one or more additional elements, unavoidable impurities and the remainder being zinc. In an even more preferred embodiment the zinc alloy coating comprises at most 1.0 to 2.0 wt.% Mg and between 1.5 and 2.5 wt.% Al, optionally at most 0.2 wt.% of one or more additional elements, unavoidable impurities and the remainder being zinc.

The invention is also embodied in the method of providing the steel strip or sheet according to the invention wherein the strip is continuously annealed in accordance with the invention and subsequently electro-galvanised.

In another embodiment the steel strip or sheet is provided with a metallic coating layer such as a (commercially pure) aluminium layer or an aluminium alloy layer. Commercially pure aluminium contains at least 99 wt.% Al (AA 1XXX-series). A typical metal bath for a hot-dip coating with an aluminium alloy layer comprises of aluminium alloyed with silicon e.g. aluminium alloyed with 8 to 11 wt.% of silicon and at most 4 wt.% of iron, optionally at most 0.2 wt.% of one or more additional elements such as calcium, unavoidable impurities, the remainder being aluminium. Silicon is present in order to prevent the formation of a thick iron-intermetallic layer which reduces adherence and formability. Iron is preferably present in amounts between 1 and 4 wt.%, more preferably at least 2 wt.%.

Although the thickness of the cold-rolled strip or sheet is not particularly limiting, it is still preferable that the thickness of the steel strip or sheet is between 0.50 and 1.20 mm.

In an embodiment the grain size of the ferrite grains in the cold-rolled steel strip and sheet according to the invention is between 9 and 13 ASTM, and preferably between 9.5 and 12 ASTM, more preferably at least 10 ASTM.

Preferably one, more or all of Cr, V, Cu, Ni and/or Mo are present only as inevitable impurities in the steel according to the invention, and more preferably one, more or all of Cr, V, Cu, Ni and/or Mo are completely absent.

According to a second aspect, the invention is also embodied in the method for producing a cold-rolled and annealed bake-hardenable steel hot-dip galvanised strip or sheet having a chemical composition in wt.% comprising:

- producing a steel melt and continuous casting a slab or strip having a composition comprising, in wt.%:
  - C: 0.0022 to 0.0042;
  - Al_sol: 0.027 to 0.066;
  - Nb: 0.004 to 0.028;
  - B: 0.0004 to 0.0017;

- Ti: 0.004 to 0.014;
- N: 0.0004 to 0.0033;
- S: 0.022 or less;
- Cr: 0.045 or less;
- V: 0.005 or less;
- Cu: 0.045 or less;
- Ni: 0.045 or less;
- Mo: 0.011 or less;
- $1.445 \leq Mn$ (in wt.%) $+10 * P$ (in wt.%) $+ Si$ (in wt.%) ≤ 1.925;
- wherein the silicon content is at least 0.148 and/or at most 0.248 wt.%;
- Ca: 0 to 0.0100;

the remainder being Fe and inevitable impurities;

- heating or reheating the slab to a temperature of at least 1050 °C followed by hot-rolling the slab to produce a hot-rolled strip having a thickness of at most 5.0 mm, wherein the finish rolling temperature is above Ar3, and cooling the hot-rolled strip to the coiling temperature of not lower than 650 °C at a cooling rate of at least 40 °C/s;
- post-processing the hot-rolled strip by means of pickling;
- cold-rolling the post-processed hot-rolled strip with a cold-rolling reduction of between 65 and 90%;
- continuous annealing the cold-rolled strip to transform the cold-rolled microstructure into a recrystallised microstructure, followed by providing the annealed strip with a metal coating in a hot-dip galvanising step;
- temper rolling the hot-dip galvanised steel strip at a temper rolling reduction of at least 0.2%;
- optionally post-processing the temper-rolled steel strip such as coiling, cutting into sheets, forming, etc.;

wherein the yield strength (Rp) is between 270 and 330 MPa, the tensile strength (Rm) is between 360 and 460, the total strain (A80) is at least 28%, the n0-value is at least 0.13, the r0-value is at least 1.10, and a bake-hardening index (BH2) of at least 30 MPa, all measured // RD.

In an embodiment the process conditions of the method according to the invention according to the invention are selected as follows:

- heating or reheating the slab to a temperature of at least 1100 °C or even at least 1150 °C;
- the finish rolling temperature is between 900 and 945 °C;

- the coiling temperature of the middle of the strip is not lower than 710 °C and/or not higher than 750 °C;
- the cold-rolling reduction is at least 68%, preferably 70% and more preferably at least 75% and/or at most 90%;
- temper rolling the hot-dip galvanised steel strip between 0.2 and 2.5%, preferably between 1.25 and 2.10%.

It is noted that these process conditions can be selected independent of each other, so that the process according to the invention embodies one, more or all of these process conditions.

It is also noted that the coiling temperature of the head end and the tail end may be higher than the coiling temperature of the middle of the strip to compensate for the faster cooling rate of the head and tail after coiling. This compensation is important to promote certain metallurgical reactions such as precipitation of AlN or NbC. In that case a so-called U-type cooling may be employed wherein the head and tail are coiled at a higher temperature (see figure 3). The temperature difference between the head/tail and middle section of such a cooling that is required to compensate for the tail/head effects can be easily determined by the skilled person, but as a general indication the coiling temperature of the head and tail may be about 30 °C higher than the middle of the strip. It should be noted that the head and tail ends are relatively short as compared to the middle section. The optimal length of the head and tail ends in comparison to the middle section, the length of the transfer between head/tail and the middle and the temperature differential over the length of the strip can be easily determined with a thermal model that calculates the cooling of every point in a coil and coupled with a metallurgical model for precipitation of e.g. AlN the optimum temperature path can be derived (Metallurgy for Hoogovens' new CA line for tin plate, Th.M. Hoogendoorn, A.J. van den Hoogen, 1991 TMS Fall Meeting, Cincinnati (OH), October 22-24, 1991).

Examples

The invention will now be further explained by means of the following non-limiting examples.

Table 1: chemical composition and main process settings of test materials.

coil	C	Mn	P	S	Si	Al zo	B	Nb	Ti	Mn+Si+10*P	reheat	FRT	CTM	CR red	TM red
id	ppm	m%	m%	m%	m%	m%	ppm	m%	m%	m%	°C	°C	°C	%	%
A	39	734	80	8	195	43	11,4	7	9	1729	1210	924	728	80	1,5
B	36	759	81	8	192	43	10,7	7	9	1761	1222	911	733	75,1	1,5
C	31	708	77	8	183	45	11,8	8	9	1661	1214	907	730	75,1	2
D	32	741	80	8	196	46	8	7	9	1737	1210	916	731	77,1	1,5
E	33	739	80	7	196	46	6,7	7	9	1735	1208	919	732	77,1	2
F	33	725	79	8	191	46	6,7	7	9	1706	1202	926	732	80	2
G	35	744	81	8	196	44	7,1	7	9	1750	1220	937	730	80	1,5
H	34	755	82	8	196	44	7,2	7	9	1771	1220	950	730	80	2
I	30	696	75	8	175	46	7	7	9	1621	1188	937	758	77,1	1,5
J	33	684	73	8	165	47	6	7	9	1579	1188	943	733	77,1	1,5
O	31	*606*	62	8	*114*	46	7,5	7	9	*1340*	1188	919	744	77,1	1,5
R	28	*625*	65	8	*126*	46	8,6	7	9	*1401*	1184	941	734	77,1	1,5
S	27	*607*	63	8	*117*	45	6,4	7	9	*1354*	1184	932	731	77,1	1,5
T	33	*598*	61	8	*107*	45	7,9	7	9	*1315*	1184	942	736	77,1	1,5

Alloys A to J are according the invention. Alloys O to T are outside the claims of this invention and are shown to demonstrate the effect of the chemistry and processing.

The steels have all been produced in a Basic Oxygen Steelmaking-plant and continuously cast as thick slabs (~225 mm). It should be noted that the steels could also be produced by thin slab casting and direct hot rolling, in which case the thickness of the cast slab is usually between 50 and 100 mm. This does not affect the properties of the final inventive product. A non-limiting schematic overview of the production is depicted in figure 1.

The steel slabs were reheated in the slab reheating furnace (SRF) to a temperature of at least 1050 °C and subsequently hot-rolled to thicknesses of 2.8, 3.1 and 3.5 mm. The finish hot rolling temperature (FRT) was above Ac3, so the hot-rolling was performed in the austenitic state. A target FRT of between about 910 °C to 930 °C was used. After cooling the hot-rolled strip on the run-out table (ROT) the strips were coiled at a target coiling temperature (CT) of 730 °C. The hot-rolled coils (HRC) were subsequently pickled and cold-rolled to a thickness of 0.70 mm, resulting in a cold rolling reduction of 75, 77 and 80% (depending on the thickness of the HRC). The cold-rolled coils (CRC) were subsequently continuously annealed to get full recrystallisation, and 1.4 to 2.0% temper rolled. In between the annealing and the temper rolling the coils are hot-dip galvanised, to provide the strip with a metal coating layer to produce a cold-rolled metal coated coil (CRCC).

The microstructures of the cold-rolled metal coated coils show a fully recrystallised microstructure with a grainsize between 10 and 10.5 ASTM. The mechanical properties are given in table 2.

Table 2: Mechanical properties of test materials.

	Longitudinal							diagonal							Transverse						
coil id	Rp MPa	Rm MPa	Ag %	A80 %	n	r	BH2 MPa	Rp MPa	Rm MPa	Ag %	A80 %	n	r	BH2 MPa	Rp MPa	Rm MPa	Ag %	A80 %	n	r	BH2 MPa
A	295	417	19,9	32,7	0,186	1,437	54,4	299	414	19,3	31,7	0,179	1,565		300	413	19,2	32,4	0,179	1,983	52,5
B	306	422	18,6	32,1	0,178	1,365	57,0	308	420	18,1	32,2	0,171	1,570		311	422	18,4	33,5	0,172	1,686	57,5
C	299	414	18,1	32,1	0,171	1,378	49,2	305	411	17,6	33,0	0,167	1,562		310	413	17,9	31,7	0,165	1,650	49,3
D	298	420	18,9	32,1	0,180	1,399	51,1	306	419	18,7	33,9	0,174	1,406		310	420	18,7	35,3	0,173	1,631	53,2
E	314	415	18,3	33,6	0,164	1,436	51,8	307	417	18,9	33,5	0,171	1,311		324	424	17,5	33,2	0,160	1,753	45,8
F	313	418	18,7	33,3	0,168	1,421	50,5	313	411	18,1	33,9	0,162	1,460		316	419	17,4	32,4	0,161	1,841	49,2
G	304	419	19,2	33,5	0,179	1,385	55,7	301	412	19,0	32,9	0,174	1,270		309	419	18,1	28,9	0,171	1,531	54,3
H	314	419	18,3	32,9	0,167	1,453	51,5	311	414	17,9	33,4	0,161	1,274		316	419	17,5	32,6	0,158	1,682	51,3
I	285	405	19,8	36,3	0,183	1,347	48,5	294	407	18,4	35,0	0,169	1,665		296	407	18,1	34,0	0,170	1,991	
J	277	400	18,7	35,2	0,175	1,384	47,6	278	399	17,9	35,3	0,166	1,507		286	402	17,4	32,5	0,163	1,867	47,2
O	269	388	19,1	36,0	0,175	1,464	50,8	280	391	18,2	35,8	0,166	1,574		281	387	18,1	31,7	0,168	1,821	46,7
R	265	389	18,9	34,5	0,177	1,386	45,8	268	390	18,0	32,2	0,167	1,580		274	390	18,5	35,8	0,172	1,790	42,0
S	260	382	19,6	37,5	0,183	1,425	45,6	261	382	19,8	37,0	0,182	1,444		264	382	19,1	34,7	0,178	1,726	47,5
T	266	383	19,4	36,3	0,180	1,464	48,8	271	384	18,8	34,4	0,172	1,472		273	383	18,7	34,4	0,173	1,940	45,3

An analysis of the results shows that the strength does indeed depend on the levels of Mn, Si and P. Coils having a composition outside the claimed ranges do not guarantee the required minimum strength of 270 MPa.

A further analysis of the tensile properties as function of the cold rolling reduction reveals that R_{p02}, R_m, A_g, A_{80} and the n-value do not depend on the cold reduction, only the r-value is affected by the cold reduction. The results in table 2 show that yield strength (R_p), tensile strength (R_m) and elongation (A_{80}) and the r-value are not or hardly affected by the temper mill setting, while the uniform elongation (Ag) and n-value (strain hardening exponent) somewhat decrease with higher temper mill reduction. A higher temper mill reduction leads to more work hardening in the material and, as a result, to lower initial A_g and n-values. The increase in yield strength by increasing the temper mill reduction from 1.5 to 2.0% is only ~3 MPa.

The cold-rolled metal coated coils were produced as standard Full Finish (FF). The roughness of the rolling cylinders in the last stand of the cold mill (#5) was about 5,8 µm EDT. Roughness and waviness were measured at the middle of the coil (over the length) according to SEP1941 (May 2012) after deformation as described in SEP1942 (draft, May 2017). The results are summarized in table 3 which also includes some relevant process settings.

Table 3: Coiling temperature, roughness and waviness values.

coil id	CTM [°C]	Ra [µm]	Wsa [µm]
A	728	1,34	0,36
B	733	1,28	0,32
C	730	1,30	0,31
D	731	1,27	0,31
E	732	1,41	0,33
F	732	1,36	0,35
G	730	1,27	0,36
H	730	1,29	0,41

Brief description of the drawings

The invention will now be explained by means of the following, non-limiting figures.

Figure 1: Schematic production process.

Figure 2: Rp (in MPa) as a function of $\Sigma(Mn+Si+10\cdot P)$ in wt.%.

Figure 3: U-type run-out table cooling.

In figure 1 the production process of the steel according to the invention is schematically shown. The process starts with the casting and ends with the cold-rolled galvanised coil (CRGC). The intermediary steps are schematically shown.

Figure 2 shows the relation between one of the mechanical properties (Rp in MPa) as a function of $\sum(Mn+Si+10\cdot P)$ (in wt.%) which shows the improvement that the steel and the process according to the invention offers. The vertical dashed lines show the values for 1.445 and 1.925 wt.%, the horizontal dashed line shows Rp=270 MPa.

Figure 3 shows a schematic drawing of the U-type cooling, and a specification of the head section, middle section and tail section of a strip. The head section is the section that is hot-rolled first and therefore end up as the inner wraps in the "eye" of the coil and the tail section is the section that is hot-rolled last and therefore end up as the outer wraps of the coil. The length of the middle section depends on the thickness of the strip, the width of the strip and the weight of the coil.

CLAIMS

1. A cold-rolled and annealed bake-hardenable steel hot-dip galvanised or electro-galvanised strip or sheet having a chemical composition comprising:
   - C: 0.0022 to 0.0042 wt.%;
   - Al_sol: 0.027 to 0.066 wt.%;
   - Nb: 0.004 to 0.028 wt.%;
   - B: 0.0004 to 0.0017 wt.%;
   - Ti: 0.004 wt.% to 0.014 wt.%;
   - N: 0.0004 to 0.0033 wt.%;
   - S: 0.022 wt.% or less;
   - Cr: 0.045 wt.% or less;
   - V: 0.005 wt.% or less;
   - Cu: 0.045 wt.% or less;
   - Ni: 0.045 wt.% or less;
   - Mo: 0.011 wt.% or less;
   - $1.445 \leq Mn + 10 * P + Si \leq 1.925$ wt.%
   - Ca: 0 to 0.0100 wt.%;
   - wherein the silicon content is at least 0.148 and/or at most 0.248 wt.%;

   the remainder being Fe and inevitable impurities;

   wherein the yield strength (Rp) // RD is between 270 and 330 MPa, the tensile strength (Rm) // RD is between 360 and 460, the total strain (A80) // RD is at least 28%, the n0-value is at least 0.13, the r0-value is at least 1.10, and a bake-hardening index (BH2) of at least 30 MPa, wherein Rp, Rm, A80, n0 and r0 are determined according to VDA239-100:2016 and BH2 according to EN10325:2002, and wherein // RD means that the property is measured on a tensile specimen with its longitudinal direction being parallel to the rolling direction.

2. The steel strip or sheet according to claim 1 having a roughness value (Ra) of between 0.80 and 1.50 µm and wherein the waviness Wsa(1-5) after 5% deformation as described in SEP 1941 and 1942 is at most 0.37 µm.

3. The steel strip or sheet according to claim 1 or 2 wherein the phosphorus content is at least 0.054 and/or at most 0.099 wt.%.

4. The steel strip or sheet according to any one of claims 1 to 3 wherein the manganese content is at least 0.610 and/or at most 0.880 wt.%.

5. The steel strip or sheet according to any one of claims 1 to 4 wherein Mn (wt.%) +10 * P (wt.%) + Si (wt.%)) is at most 1.825 and/or at least 1.525.

6. The steel strip or sheet according to any one of claims 1 to 5 wherein the galvanisation layer is a metallic coating layer, such as zinc or a zinc alloy coating layer, or wherein the galvanisation layer is a metallic coating layer, such as a commercially pure aluminium layer containing at least 99 wt.% Al or an aluminium alloy layer.

7. The steel strip or sheet according to claim 6 wherein the zinc-alloy coating layer comprises 0.3-4.0 wt.% Mg and 0.3-6.0 wt.% Al and optionally at most 0.2 wt.% of one or more additional elements, the remainder being unavoidable impurities and zinc.

8. The steel strip or sheet according to any one of claims 1 to 7 wherein the thickness of the steel strip or sheet is between 0.50 and 1.20 mm.

9. A method for producing a cold-rolled and annealed bake-hardenable steel hot-dip galvanised or electro-galvanised strip or sheet having a chemical composition comprising, in wt.%:

- producing a steel melt and continuous casting a slab or strip having a composition comprising, in wt.%:
  - C: 0.0022 to 0.0042;
  - Al_sol: 0.027 to 0.066;
  - Nb: 0.004 to 0.028;
  - B: 0.0004 to 0.0017;
  - Ti: 0.004 to 0.014;
  - N: 0.0004 to 0.0033;
  - S: 0.022 or less;
  - Cr: 0.045 or less;
  - V: 0.005 or less;
  - Cu: 0.045 or less;
  - Ni: 0.045 or less;
  - Mo: 0.011 or less;
  - $1.445 \leq Mn + 10 * P + Si \leq 1.925$ wt.%;
  - Ca: 0 to 0.0100;
  - wherein the silicon content is at least 0.148 and/or at most 0.248 wt.%;

  the remainder being Fe and inevitable impurities;

- heating or reheating the slab to a temperature of at least 1050 °C followed by hot-rolling the slab to produce a hot-rolled strip having a thickness of at most 5.0 mm, wherein the finish rolling temperature is above Ar3, and cooling the hot-rolled strip to the coiling temperature of not lower than 650° C at a cooling rate of at least 40 °C/s;
- post-processing the hot-rolled strip by means of pickling;
- cold-rolling the post-processed hot-rolled strip with a cold-rolling reduction of between 65 and 90%;
- continuous annealing the cold-rolled strip to transform the cold-rolled microstructure into a recrystallised microstructure, followed by providing the annealed strip with a metal coating in a galvanising step;
- temper rolling the galvanised steel strip at a temper rolling reduction of at least 0.2%;
- optionally post-processing the temper-rolled steel strip;

wherein the yield strength (Rp) is between 270 and 330 MPa, the tensile strength (Rm) is between 360 and 460, the total strain (A80) is at least 28%, the n0-value is at least 0.13, the r0-value is at least 1.10, and a bake-hardening index (BH2) of at least 30 MPa, all measured // RD.

10. The method according to claim 9 wherein the galvanising step is a hot-dip galvanising step.

11. The steel strip or sheet produced according to claim 9 or 10 having one, two or all of P, Mn and Si in the following amounts:
    - phosphorus content is at least 0.054 and/or at most 0.099 wt.%;
    - the manganese content is at least 0.610 and/or at most 0.880 wt.%;Mn + 10 * P + Si is at most 1.825 and/or at least 1.525 wt.%.

12. The method according to any one of claims 9 to 11 wherein one, more or all of the process conditions are as follows:
    - heating or reheating the slab to a temperature of at least 1100 °C or even at least 1150 °C;
    - the finish rolling temperature is between 900 and 945 °C;
    - the coiling temperature is not lower than 710 °C and/or not higher than 750 °C;
    - the cold-rolling reduction is at least 75 and/or at most 83%;
    - temper rolling the hot-dip galvanised steel strip between 0.2 and 2.5%, more preferred between 1.25 and 2.10%.

13. The method according to any one of claims 9 to 12 wherein the coiling temperature of the middle section of the strip is not lower than 710 °C and/or not higher than 750 °C, and wherein the head and tail end of the strip is coiled at a higher temperature, preferably wherein the head and tail end of the strip is coiled at a temperature that is at least 10 and at most 50 °C higher than the coiling temperature of the middle section of the strip, more preferably wherein the head and tail end of the strip is coiled at a temperature that is at least 20 °C higher and/or at most 40 °C higher than the coiling temperature of the middle section of the strip.

14. The method according to any one of claims 9 to 13 wherein the galvanisation layer is a metallic coating layer, such as a zinc or a zinc alloy coating layer, or wherein the galvanisation layer is a metallic coating layer, such as a commercially pure aluminium layer containing at least 99 wt.% Al or an aluminium alloy layer.

15. The method according to claim 14 wherein the zinc alloy layer comprises 0.3-4.0 wt.% Mg and 0.3-6.0 wt.% Al and optionally at most 0.2 wt.% of one or more additional elements, the remainder being unavoidable impurities and zinc.

16. Use of the steel strip of sheet produced according to any one of claims 9 to 15 for producing parts for automotive applications, such as body parts, and outer body parts in particular.

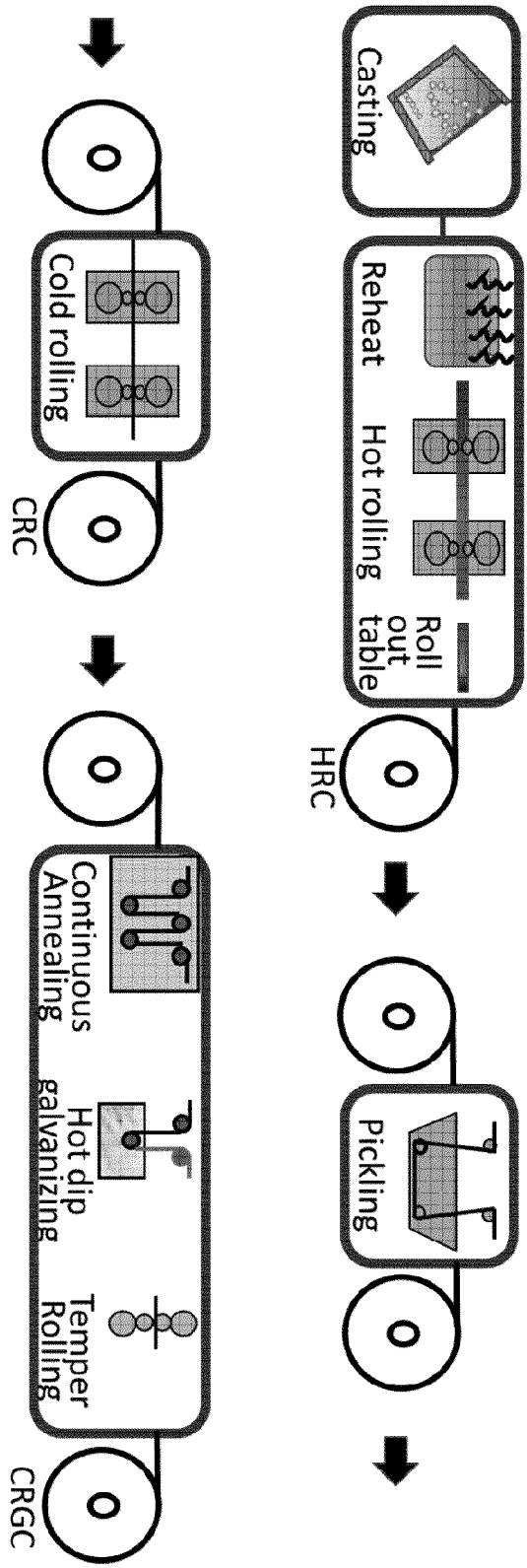

Casting
Reheat
Hot rolling
Roll out table
HRC
Pickling
Cold rolling
CRC
Continuous Annealing
Hot dip galvanizing
Temper Rolling
CRGC

FIGURE 1

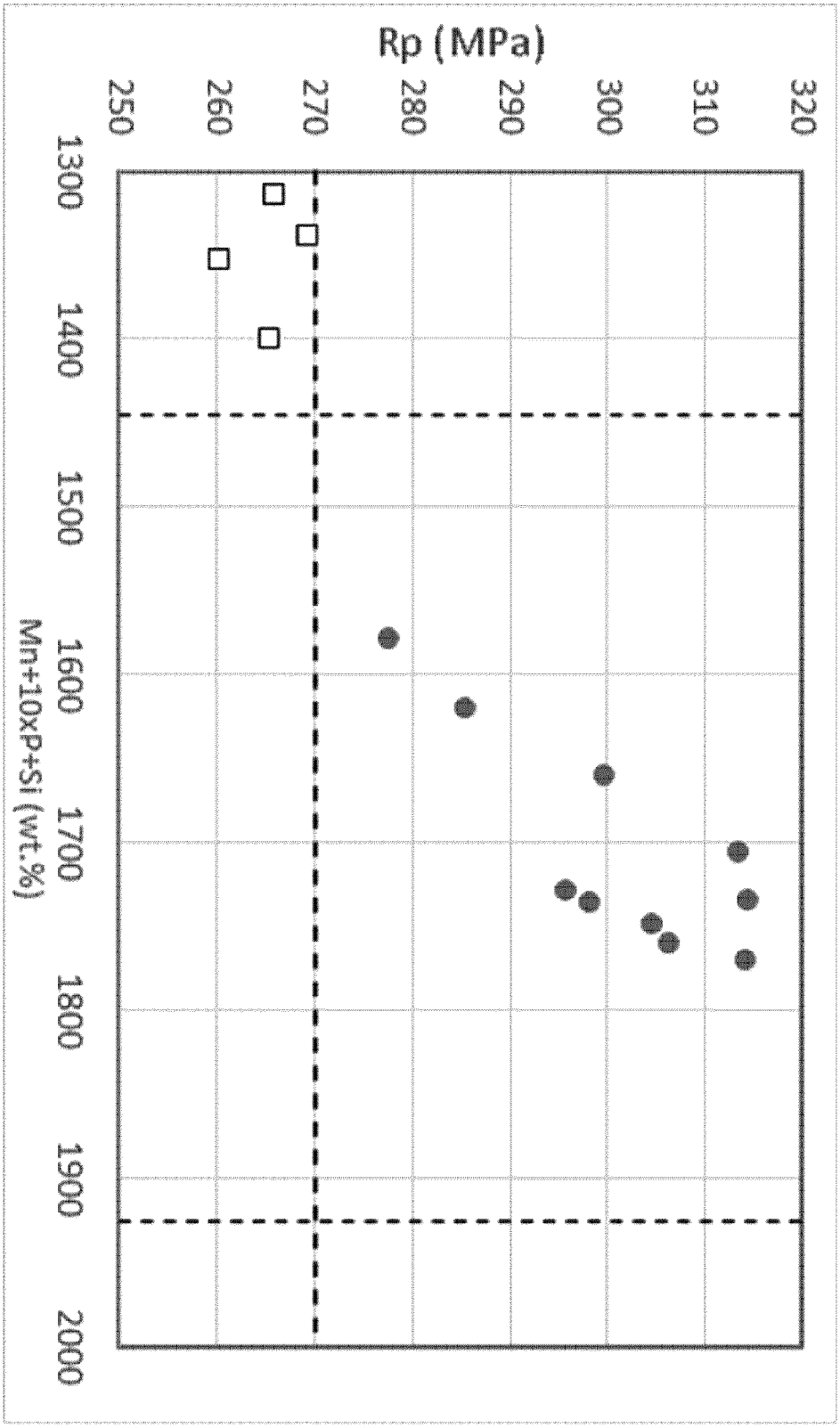
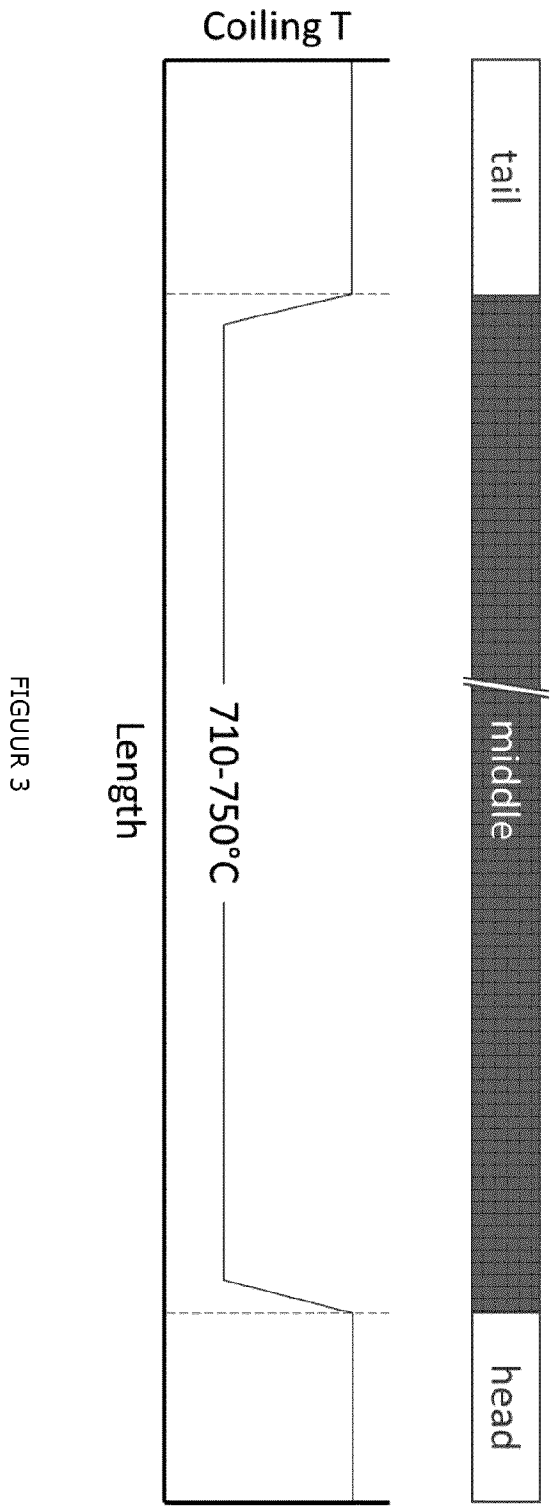

Rp (MPa)
250
260
270
280
290
300
310
320
1300
1400
1500
1600
1700
1800
1900
2000
Mn+10xP+Si (wt.%)

FIGURE 2



FIGUUR 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2022/060599

A. CLASSIFICATION OF SUBJECT MATTER
INV. C21D8/02 C22C38/00 C22C38/02 C22C38/04 C22C38/12
C23C2/00 C21D9/46 C23C2/02 C23C2/06 C23C2/12
C23C2/28 C23C2/40

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 B21B

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.
A	JP H06 322441 A (SUMITOMO METAL IND) 22 November 1994 (1994-11-22) Table 1, example D; paragraphs [0017], [0039], [0046]; tables 1, 2	1-16
A	JP H06 299290 A (NIPPON STEEL CORP) 25 October 1994 (1994-10-25) Table 2: example C; paragraphs [0019] - [0021], [0024] - [0026]; tables 2-4	1-16
A	JP H11 335781 A (KOBE STEEL LTD) 7 December 1999 (1999-12-07) Table 1, a-b; paragraphs [0029], [0030]	1-16

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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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 August 2022	16/08/2022

Name and mailing address of the ISA/	Authorized officer
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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International application No
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