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(54) **COILING TEMPERATURE INFLUENCED COLD ROLLED STRIP OR STEEL**

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(57) **ABSTRACT**

A cold roll strip or sheet includes in (wt %) C 0.08-0.28; Mn 1.4-4.5; Cr 0.01-0.5; Si 0.01-2.5; Al 0.01-0.6; Si+Al≥0.1; Si+Al+Cr≥0.4; Nb≤0.008; Ti≤0.02; Mo≤0.08; Ca≤0.005; V≤0.02; balance Fe apart from impurities. The steel is within the area defined by the coordinates A, B, C, D, where Ri/t (y-axle) is plotted vs TS(MPa)/YR (x-axle), and where A is [1200, 2), B is [2000, 4], C is [2000, 3], and D is [1200, 1].

Fig 1

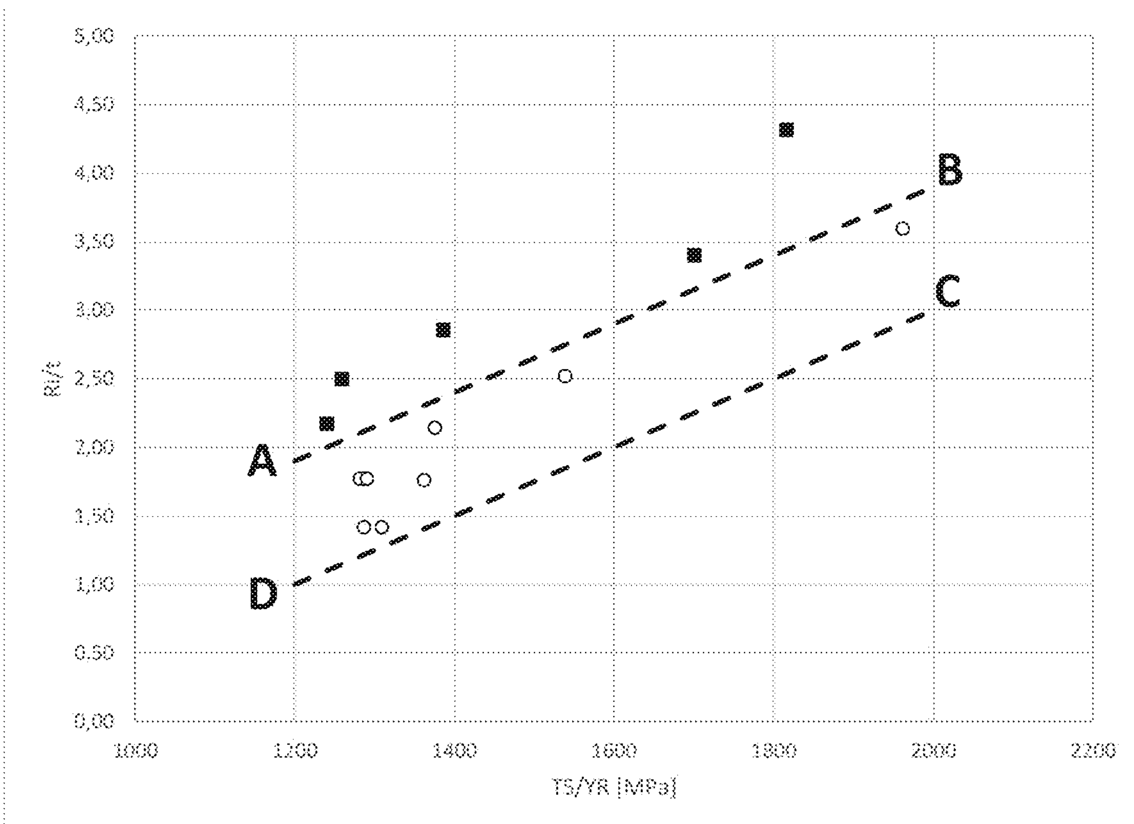

5,00
4,50
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
Ri/t
1000
1200
1400
1600
1800
2000
2200
TS/YR [MPa]
A
B
C
D

Fig 2a

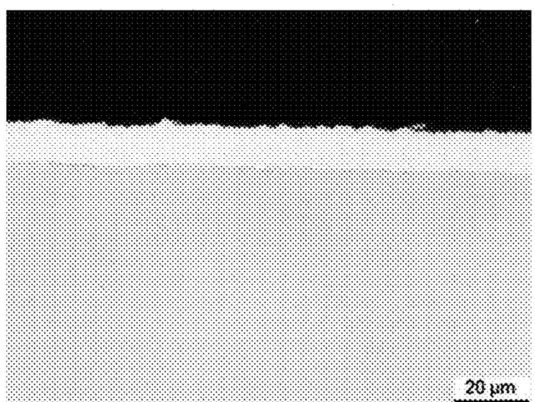


Fig 2b

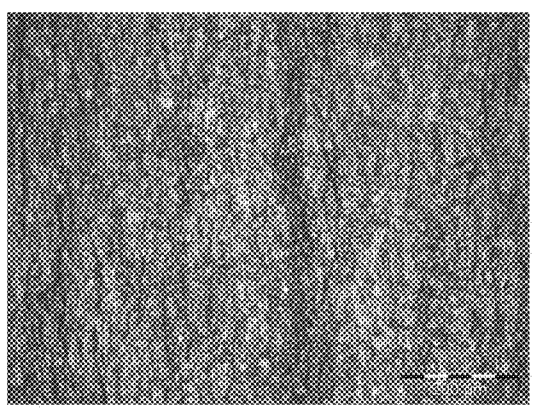


Fig 3a

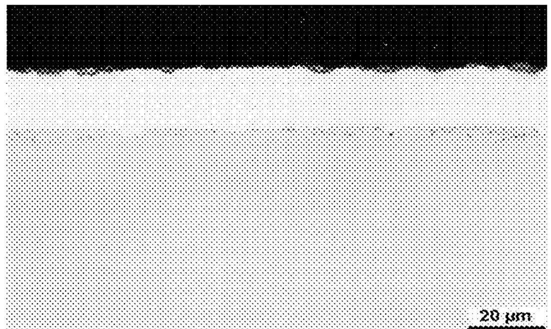


Fig 3b

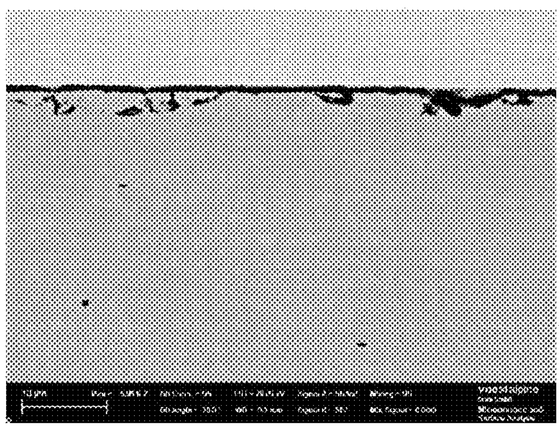


Fig 3c

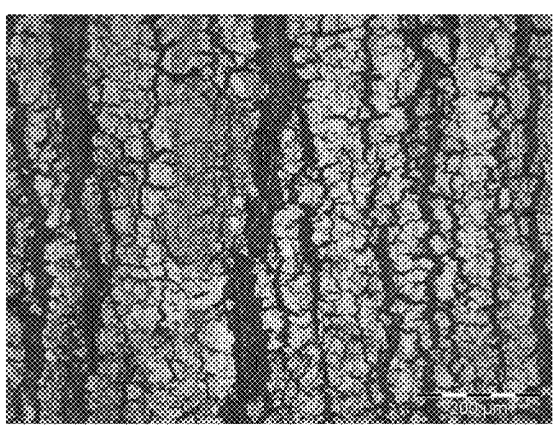


Fig 4

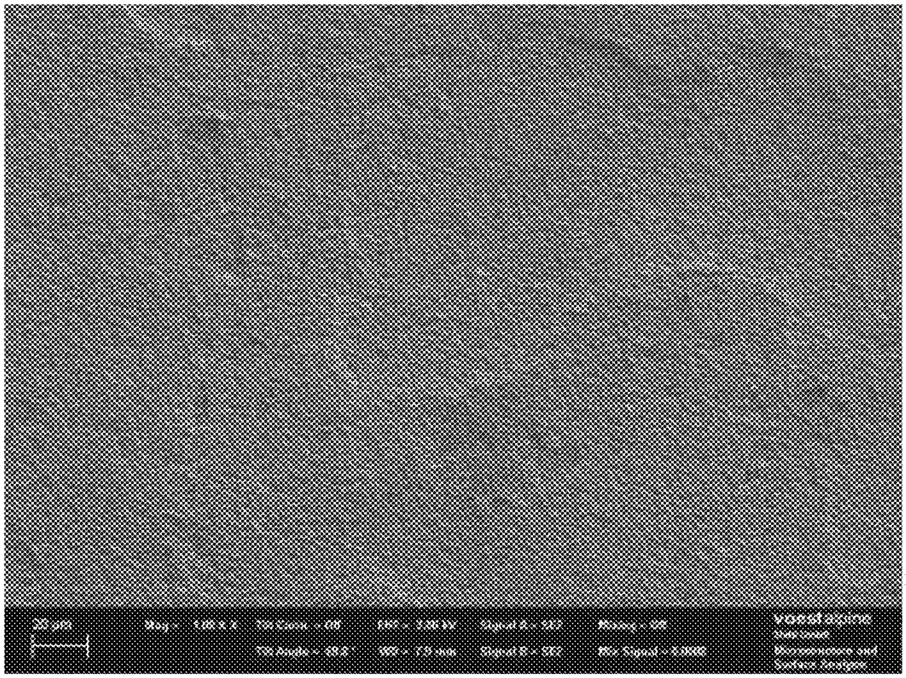
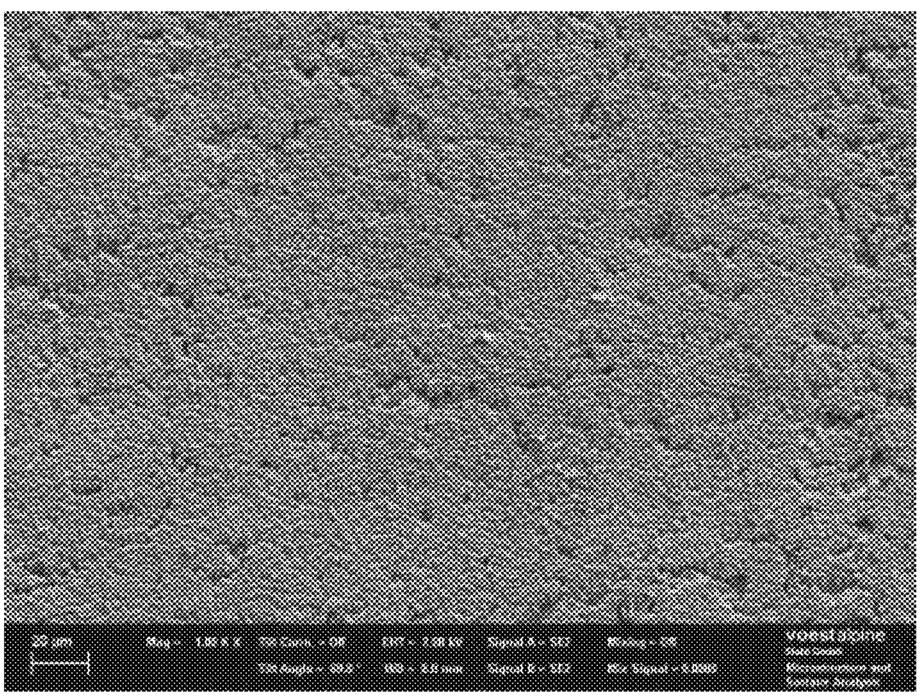


Fig 5



COILING TEMPERATURE INFLUENCED COLD ROLLED STRIP OR STEEL

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This is a National Stage Entry into the United States Patent and Trademark Office from International Patent Application No. PCT/EP2021/087596, filed on Dec. 23, 2021, which relies on and claims priority to Swedish Patent Application No. 2051557-3, filed on Dec. 23, 2020, the entire contents of both of which are incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to high strength steel strips and sheets suitable for applications in automobiles.

BACKGROUND OF THE INVENTION

[0003] For a great variety of applications increased strength levels are a pre-requisite for light-weight constructions in particular in the automotive industry, since car body mass reduction results in reduced fuel consumption.

[0004] Automotive body parts are often stamped out of sheet steels, forming complex structural members of thin sheet. However, such parts cannot be produced from conventional high strength steels, because of a too low formability of the complex structural parts. For this reason, multi-phase Transformation Induced Plasticity aided steels (TRIP steels) have gained considerable interest in the last years, in particular for use in auto body structural parts and as seat frame materials.

[0005] TRIP steels possess a multi-phase microstructure, which includes a meta-stable retained austenite phase, which is capable of producing the TRIP effect. When the steel is deformed, the austenite transforms into martensite, which results in remarkable work hardening. This hardening effect acts to resist necking in the material and postpones failure in sheet forming operations. The microstructure of a TRIP steel can greatly alter its mechanical properties.

[0006] TRIP steels have been known for long and attracted a lot of interest, mainly because the matrix allows an excellent stretch flangability. Moreover, the TRIP effect ensured by the strain-induced transformation of metastable retained austenite islands into martensite, remarkably improves their drawability.

[0007] When producing cold rolled TRIP steel sheets a slab is initially provided. The slab is hot rolled in austenitic temperature range to a hot rolled strip. The hot rolled strip is thereafter coiled. The coiling resistance is reduced with increasing temperature. Commonly a coiling temperature of 600° C. is employed. The coiled strip is thereafter batch annealed, followed by cold rolling. The cold rolled strip is thereafter continuously annealed.

[0008] WO 2019/122963 A1 and WO2019123043 A1 both discloses a TRIP steel with improved phosphatation coverage. A good phosphatation coverage is enabled. The improved phosphatation coverage was achieved by controlling the alloying elements and the process parameters of which one is to have a low coiling temperature. All inventive examples have a coiling temperature of 450° C. Reference examples with higher coiling temperatures did not provide sufficient phosphatation coverage. A low coiling temperature increases cold rolling forces.

[0009] EP 2707514 B1 disclose a TRIP steel having a microstructure comprising of 5-20% polygonal ferrite, 10-15% residual austenite, 5-15% martensite and balance bainite. According to the document the presence of polygonal ferrite between 5 and 20% makes it possible to exceed a V-bending angle of 90° without the occurrence of cracking.

[0010] WO2018116155 disclose a TRIP steel. The inventive examples disclose a lower coiling temperature of 450° C. in combination with a higher batch annealing temperature of 620° C. respectively 650° C., and a higher coiling temperature of 560° C. in combination with a lower batch annealing temperature of 460° C.

[0011] EP 3 653 738 A1 discloses a TRIP steel having a microstructure comprising of 3-15% residual austenite, at least 30% tempered martensite, at most 5% fresh martensite, at most 35% bainite, 5-15% martensite, 5-35% ferrite.

[0012] Although these steels disclose several attractive properties there is demand for >950 MPa steel sheet or strip having an improved property profile with respect to advanced forming operations, in particular bending properties. In particular bending property in relation to strength and toughness. Further desirable properties are: reduced grain-boundary oxidation, reduced susceptibility to Liquid metal embrittlement, reduced susceptibility to hydrogen embrittlement, and a good phosphatability.

[0013] US 2020/347473 A1 discloses a ferrite phase of 2-15%. According to US 2020/347473 A1 a microstructure free of ferrite phase exhibits unsatisfactory hardenability and ductility, and, consequently cracking results due to insufficient ductility or stress concentration during bending. According to US 2020/347473 A1 it is therefore required to control both the average grain size and the area ratio of the ferrite phase.

[0014] WO 2020/151856 A1 and EP 3 686 293 A1 are Titanium and Boron micro alloyed steels. Boron increases hardness but may come at a cost of reduced bendability. Boron can further make scrap recycling more difficult and may deteriorate workability.

SUMMARY OF THE INVENTION

[0015] The present invention is directed to cold rolled steels having a tensile strength of at least 950 MPa and an excellent formability, wherein it should be possible to produce the steel sheets/strips on an industrial scale in a Continuous Annealing Line (CAL) and in a Hot Dip Galvanizing Line (HDGL).

[0016] The invention aims at providing a steel having a composition and microstructure that can be processed to complicated high strength structural members, where the bending properties are of importance.

[0017] The careful selection of alloying elements and process parameters reduces grain boundary oxidation. The reduced grain boundary oxidation improves bendability and reduces the risk of liquid metal embrittlement and susceptibility to hydrogen embrittlement. It further facilitates good phosphatability.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIG. **1** shows a graph with the inventive samples within a within the dotted lines.

[0019] FIG. **2***a* shows no an inventive sample with no grain boundary oxidation.

[0020] FIG. **2***b* shows the surface of the inventive sample of FIG. **2***a*.

[0021] FIG. **3***a* shows the grain boundary oxidation of a reference sample.

[0022] FIG. **3***b* is a zoom in on the grain boundary of FIG. **3***a*.

[0023] FIG. **3***c* shows the surface of the reference sample of FIG. **3***a*-**3***b*.

[0024] FIG. **4** shows the phosphatation coverage of the inventive sample FIG. **2***a*-**2***b*.

[0025] FIG. **5** shows the phosphatation coverage of the reference sample of FIG. **3***a*-**3***c*.

DETAILED DESCRIPTION OF EMBODIMENT(S) OF THE INVENTION

[0026] The invention is described in the paragraphs that follow.

[0027] The steel sheet has a composition consisting of the following alloying elements (in wt. %):

C	0.08-0.28
Mn	1.4-4.5
Cr	0.01-0.5
Si	0.01-2.5
Al	0.01-0.6
Si + Al	≥0.1
Si + Al + Cr	≥0.4
Nb	≤0.1
Ti	≤0.1
Mo	≤0.5
Ca	≤0.05
V	≤0.1

[0028] balance Fe apart from impurities.

[0029] The importance of the separate elements and their interaction with each other as well as the limitations of the chemical ingredients of the claimed alloy are briefly explained in the following. All percentages for the chemical composition of the steel are given in weight % (wt. %) throughout the description. Upper and lower limits of the individual elements can be freely combined within the limits set out in the claims. The arithmetic precision of the numerical values can be increased by one or two digits for all values given in the present application. Hence, a value of given as e.g. 0.1% can also be expressed as 0.10 or 0.100%. The amounts of the microstructural constituents are given in volume % (vol. %).

C: 0.08-0.28%

[0030] C stabilizes the austenite and is important for obtaining sufficient carbon within the retained austenite phase. C is also important for obtaining the desired strength level. Generally, an increase of the tensile strength in the order of 100 MPa per 0.1% C can be expected. When C is lower than 0.08% it is difficult to attain a tensile strength of 950 MPa. If C exceeds 0.28%, then the weldability is impaired. The upper limit may thus be 0.26, 0.24, 0.22, 0.20 or 0.18%. The lower limit may be 0.10, 0.12, 0.14, or 0.16%.

Mn: 1.4-4.5%

[0031] Manganese is a solid solution strengthening element, which stabilises the austenite by lowering the M_s temperature and prevents ferrite and pearlite to be formed during cooling. In addition, Mn lowers the A_{c3} temperature and is important for the austenite stability. At a content of less than 1.5% it might be difficult to obtain the desired amount of retained austenite, a tensile strength of 950 MPa and the austenitizing temperature might be too high for conventional industrial annealing lines. In addition, at lower contents it may be difficult to avoid the formation of polygonal ferrite. However, if the amount of Mn is higher than 4.5%, problems with segregation may occur because Mn accumulates in the liquid phase and causes banding, resulting in a potentially deteriorated workability. The upper limit may therefore be 4.2, 4.0, 3.8, 3.6, 3.4, 3.2, 3.0, 2.8, 2.6, or 2.4%. The lower limit may be 1.5, 1.7, 1.9, 2.1, 2.3, or 2.5%.

Cr: 0.01-0.5%

[0032] Cr is effective in increasing the strength of the steel sheet. Cr is an element that forms ferrite and retards the formation of pearlite and bainite. The A_{c3} temperature and the M_s temperature are only slightly lowered with increasing Cr content. Cr results in an increased amount of stabilized retained austenite. When above 0.5% it may impair surface finish of the steel, and therefore the amount of Cr is limited to 0.5%. The upper limit may be 0.45 or 0.40, 0.35, 0.30 or 0.25%. The lower limit may be 0.01, 0.03, 0.05, 0.07, 0.10, 0.15, 0.20 or 0.25%. Preferably, a deliberate addition of Cr is not conducted according to the present invention.

Si: 0.01-2.5%

[0033] Si acts as a solid solution strengthening element and is important for securing the strength of the thin steel strip. Si suppresses the cementite precipitation and is essential for austenite stabilization. However, if the content is too high, then too much silicon oxides will form on the strip surface, which may lead to cladding on the rolls in the CAL and, as a result there of, to surface defects on subsequently produced steel sheets. The upper limit is therefore 2.5% and may be restricted to 2.4, 2.2, 2.0, 1.8 or 1.6%. The lower limit may be 0.01, 0.05, 0.1, 0.2, 0.3, 0.4, 0.60, 0.80 or 1.0%.

Al: 0.01-0.6%

[0034] Al promotes ferrite formation and is also commonly used as a deoxidizer. Al, like Si, is not soluble in the cementite and therefore it considerably delays the cementite formation during bainite formation. In addition, galvanization and reduced susceptibility to Liquid metal embrittlement can be improved. Additions of Al result in a remarkable increase in the carbon content in the retained austenite. A main disadvantage of Al is its segregation behaviour during casting. During casting Mn is enriched in the middle of the slabs and the Al-content is decreased. Therefore, in the middle of the slab a significant austenite stabilized region or band may be formed. This results at the end of the processing in martensite banding and that low strain internal cracks are formed in the martensite band. On the other hand, Si and Cr are also enriched during casting. Hence, the propensity for martensite banding may be reduced by alloying with Si and Cr, since the austenite stabilization due to the Mn enrichment is counteracted by these elements. For these reasons the Al content is preferably limited. The upper level may be 0.6, 0.5, 0.4, 0.3, 0.2, 0.1%. The lower limit may be set to 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, or 0.1%. If Al is used for deoxidation only then the upper level may then be 0.09, 0.08, 0.07 or 0.06%. For securing a certain effect the lower level may set to 0.03 or 0.04%.

Si+Al≥0.1%

[0035] Si and Al suppress the cementite precipitation during bainite formation. Their combined content is therefore preferably at least 0.1%. The upper limit may be 2%.

Si+Al+Cr≥0.4%

[0036] A certain amount of these elements is beneficial for the formation of austenite. Their combined content should therefore be at least ≥0.4%. The lower limit can be 0.5, 0.6 or 0.7%.

Mn+Cr 1.7-5.0%

[0037] Manganese and Chromium affects the hardenability of the steel. Their combined content is preferably within the range of 1.7-5.0%.

Optional Elements

Mo≤0.5%

[0038] Molybdenum is a powerful hardenability agent. It may further enhance the benefits of NbC precipitates by reducing the carbide coarsening kinetics. The steel may therefore contain Mo in an amount up to 0.5%. The upper limit may be restricted to 0.4, 0.3, 0.2, or 0.1%. A deliberate addition of Mo is not necessary according to the present invention. The upper limit may therefore be restricted to ≤0.01%.

Nb: ≤0.1%

[0039] Nb is commonly used in low alloyed steels for improving strength and toughness, because of its influence on the grain size. Nb increases the strength elongation balance by refining the matrix microstructure and the retained austenite phase due to precipitation of NbC. The steel may contain Nb in an amount of ≤0.1%. The upper limit may be restricted to 0.09, 0.07, 0.05, 0.03, or 0.01%. A deliberate addition of Nb is not necessary according to the present invention. The upper limit may therefore be restricted to ≤0.004%.

V: ≤0.1%

[0040] The function of V is similar to that of Nb in that it contributes to precipitation hardening and grain refinement. The steel may contain V in an amount of ≤0.1%. The upper limit may be restricted to 0.09, 0.07, 0.05, 0.03, or 0.01%. A deliberate addition of V is not necessary according to the present invention. The upper limit may therefore be restricted to ≤0.01%.

Ti: ≤0.1%

[0041] Ti is commonly used in low alloyed steels for improving strength and toughness, because of its influence on the grain size by forming carbides, nitrides or carbonitrides. In particular, Ti is a strong nitride former and can be used to bind the nitrogen in the steel. However, the effect tends to be saturated above 0.1%. The upper limit may be restricted to 0.09, 0.07, 0.05, 0.03, or 0.01%. A deliberate addition of Ti is not necessary according to the present invention. The upper limit may therefore be restricted to ≤0.005%.

Ca≤0.05

[0042] Ca may be used for the modification of the non-metallic inclusions. The upper limit is 0.05% and may be set to 0.04, 0.03, 0.01%. A deliberate addition of Ca is not necessary according to the present invention. The upper limit may therefore be restricted to ≤0.005%.

Impurities

Cu: ≤0.06%

[0043] Cu is an undesired impurity element that is restricted to ≤0.06% by careful selection of the scrap used.

Ni: ≤0.08%

[0044] Ni is also an undesired impurity element that is restricted to ≤0.08% by careful selection of the scrap used.

B: ≤0.0006%

[0045] B is an undesired impurity element that is restricted to ≤0.0006% by careful selection of the scrap used. B increases hardness but may come at a cost of reduced bendability and is therefore not desirable in the present suggested steel. B may further make scrap recycling more difficult and an addition of B may also deteriorate workability. A deliberate addition of B is therefore not desired according to the present invention.

[0046] Other impurity elements may be comprised in the steel in normal occurring amounts. However, it is preferred to limit the amounts of P, S, As, Zr, Sn to the following optional maximum contents:

P: ≤0.02%

S: ≤0.005%

As≤0.010%

Zr≤0.006%

Sn≤0.015%

[0047] It is also preferred to control the nitrogen content to the range:

N: ≤0.015%, preferably 0.003-0.008%

In this range a stable fixation of the nitrogen can be achieved.

[0048] Oxygen and hydrogen can further be limited to

O: ≤0.0003

H: ≤0.0020

[0049] The microstructural constituents are in the following expressed in volume % (vol. %).

[0050] The cold rolled steel sheets of the present invention have a microstructure comprising at least 50% tempered martensite (TM) and bainite (B). The lower limit may restrict to at least 60, 70%, 75%, or 80%.

[0051] And further, at most 10% fresh martensite (FM). The upper limit may be restricted 8% or 5%. Small amounts of fresh martensite may improve edge flangeability and local ductility. The lower limit may be restricted 1% or 2%. These un-tempered martensite particles are often in close contact with the retained austenite particles and they are therefore often referred to as martensite-austenite (MA) particles.

[0052] Retained austenite is a prerequisite for obtaining the desired TRIP effect. The amount of retained austenite should therefore be in the range of 2-20%, preferably 5-15%. The amount of retained austenite was measured by means of the saturation magnetization method described in detail in Proc. Int. Conf. on TRIP-aided high strength ferrous alloys (2002), Ghent, Belgium, p. 61-64.

[0053] Polygonal ferrite (PF) is susceptible to Hydrogen Embrittlement and is therefore not a desired microstructural constituent. Polygonal ferrite in combination with martensite is bad for the bending properties. Furthermore, the presence of ferrite may impart the steel with formability and elongation and also to a certain degree resistance to fatigue failure. It may also have negative impacts due to the fact that ferrite increases the gap in hardness with hard phases such as martensite and bainite and reduces local ductility, resulting in lower hole expansion ratio. Polygonal ferrite (PF) is therefore limited to ≤10%, preferably ≤5%, ≤3% or ≤1%. Most preferably, the steel is free from PF. The steel does not contain other kind of ferrite since the bending properties are affected negatively. Furthermore, the yield ratio is affected negatively by ferrite which is bad for bending properties.

[0054] The mechanical properties of the claimed steel are important, and the following requirements should be fulfilled:

TS tensile strength (R_m)	950-1550 MPa
YS yield strength ($R_{p0.2}$)	550-1400 MPa
YR yield ratio ($R_{p0.2}/R_m$)	≥0.50, preferably ≥0.7
bendability (Ri/t)	≤5

[0055] The R_m, $R_{p0.2}$ values are derived according to the European norm EN 10002 Part 1, wherein the samples are taken in the longitudinal direction of the strip. The total elongation (A_{50}) is derived in accordance with the Japanese Industrial Standard JIS Z 2241: 2011, wherein the samples are taken in the transversal direction of the strip.

[0056] The bendability is evaluated by the ratio of the limiting bending radius (Ri), which is defined as the minimum bending radius with no occurrence of cracks, and the sheet thickness, (t). For this purpose, a 90° V-shaped block is used to bend the steel sheet in accordance with JIS Z2248. The value obtained by dividing the limit bending radius with the thickness (Ri/t) should be less than 5, preferably less than 4. Ri(t) may be further limited to 3, 2.5 or 2.

[0057] A yield ratio YR is defined by dividing the yield strength YS with the tensile strength TS. Lower limit for YR can be 0.70, 0.75, 0.76, 0.77, or 0.78.

[0058] The steel should further be within the area defined by the coordinates A, B, C, D of FIG. **1**, where Ri/T (y-axle) is plotted vs TS/YR (x-axle), and where A is [1200, 2), B is [2000, 4], C is [2000, 3], and D is [1200, 1]. The upper dotted line can be mathematically expressed as y=0.0025*x−1 and the lower dotted line can be expressed as y=0.0025*x−2. This provides a criteria 1≤0.0025*TS/YR−Ri/t≤2. Steels fulfilling the criteria has been found out to have a good balance between strength and bendability. The lower limit may be 1.1, 1.2 or 1.3 and the upper limit may be 1.9 or 1.8.

[0059] The TS/YR value can further be limited such that TS/YR is within 1200-2000 (MPa). The lower limit may be 1200, 1300, 1400, 1500, 1600, 1700, or 1800. The upper limit may be 1900, 1800, 1700, 1600, 1500, or 1400. A preferred range can be 1200-1400. Other ranges can e.g. be 1400-1600, or 1600-1800, or 1800-2000.

[0060] The hole expansion ratio (λ) [HER] is preferably ≥20%. The hole expanding ratio (λ) is determined by the hole expanding test according to ISO/WD 16630:2009 (E). In this test a conical punch having an apex of 60° is forced into a 10 mm diameter punched hole made in a steel sheet having the size of 100×100 mm^2. The test is stopped as soon as the first crack is determined, and the hole diameter is measured in two directions orthogonal to each other. The arithmetic mean value is used for the calculation.

[0061] The hole expanding ratio (λ) in % is calculated as follows:

$$\lambda=(Dh-Do)/Do\times 100$$

wherein Do is the diameter of the hole at the beginning (10 mm) and Dh is the diameter of the hole after the test.

[0062] The cold rolled heat treated steel sheet of the present invention may optionally be coated with zinc or zinc alloys, or with aluminum or aluminum alloys to improve its corrosion resistance.

[0063] The suggested steel can be produced by making steel slabs of the conventional metallurgy by converter melting and secondary metallurgy with the composition suggested above. The slabs are hot rolled in austenitic range to a hot rolled strip. Preferably by reheating the slab to a temperature between 1000° C. and 1280° C., rolling the slab completely in the austenitic range wherein the hot rolling finishing temperature is greater than or equal to 850° C. to obtain the hot rolled steel strip. Thereafter the hot rolled strip is coiled at a coiling temperature in the range of 500-540° C. Optionally subjecting the coiled strip to a scale removal process, such as pickling. The coiled strip is thereafter batch annealed at a temperature in the range of 500-650° C., preferably 550-650° C., for a duration of 5-30 h. Thereafter cold rolling the annealed steel strip with a reduction rate between 35 and 90%, preferably around 40-60% reduction. Further treating the cold rolled steel strip in a Continuously Annealing Line (CAL) or in a Hot Dip Galvanizing Line (HDGL), in which the microstructure is fine tuned. Both lines include subjecting the steel to a soaking temperature of 800-1000° C., preferably 830-900° C., preferably followed by a slow jet and rapid jet cooling to a holding temperature of 200-500° C., preferably 350-450° C., for a time of 150 to 1000 s, before cooling to room temperature. The soaking temperature is above A_{c3} to avoid formation of inter critical ferrite. A_{c3} as defined by the formula A_{c3}=910-203*$C^{1/2}$−15.2 Ni−30 Mn+44.7 Si+104 V+31.5 Mo+13.1 W. Preferably the soaking temperature is at least A_{c3}+20° C., more preferably A_{c3}+30° C. Preferably the soaking temperature and time is controlled to allow for 100% austenite and no ferrite before cooling. The soaking time could e.g. be 40 s to 180 s.

[0064] M_S can be defined by the formula: M_S=692-502*$(C+0.68N)^{0.5}$−37*Mn−14*Si+20*Al−11*Cr.

[0065] The holding temperature can be above or below M_S.

[0066] In an embodiment the cold roll strip or sheet;

[0067] a) have a composition comprising of (in wt. %):

C	0.08-0.16
Mn	2.0-3.0
Cr	0.1-0.5
Si	0.5-1.2
Al	0.01-0.5
Si + Al	≥0.1
Si + Al + Cr	≥0.4
Nb	≤0.1
Ti	≤0.1
Mo	≤0.5
Ca	≤0.05
V	≤0.1

balance Fe apart from impurities; and

[0068] b) fulfil at least one of the following conditions:

TS tensile strength (R_m)	950-1150 MPa
YS yield strength ($R_{p0.2}$)	750-1000 MPa
YR yield ratio ($R_{p0.2}/R_m$)	≥0.70
bendability (Ri/t)	≤2
HER	≥20.

[0069] In another embodiment the cold roll strip or sheet;

[0070] a) have a composition comprising of (in wt. %):

C	0.15-0.25
Mn	1.0-2.0
Cr	0.1-0.5
Si	0.1-0.5
Al	0.01-0.5
Si + Al	≥0.1
Si + Al + Cr	≥0.4
Nb	≤0.1
Ti	≤0.1
Mo	≤0.5
Ca	≤0.05
V	≤0.1

[0071] balance Fe apart from impurities; and

[0072] b) fulfil at least one of the following conditions:

TS tensile strength (R_m)	1300-1550 MPa
YS yield strength ($R_{p0.2}$)	1000-1300 MPa
YR yield ratio ($R_{p0.2}/R_m$)	≥0.70
bendability (Ri/t)	≤4
HER	≥20.

[0073] In another embodiment the cold roll strip or sheet;

[0074] a) have a composition comprising of (in wt. %):

C	0.15-0.25
Mn	2.0-3.0
Cr	0.1-0.5
Si	1-2.0
Al	0.01-0.5
Si + Al	≥0.1
Si + Al + Cr	≥0.4
Nb	≤0.1
Ti	≤0.1

-continued

Mo	≤0.5
Ca	≤0.05
V	≤0.1

balance Fe apart from impurities; and

[0075] b) fulfil at least one of the following conditions:

TS tensile strength (R_m)	1100-1300 MPa
YS yield strength ($R_{p0.2}$)	900-1100 MPa
YR yield ratio ($R_{p0.2}/R_m$)	≥0.70
bendability (Ri/t)	≤3
HER	≥20.

[0076] In another embodiment the cold roll strip or sheet;

[0077] a) have a composition comprising of (in wt. %):

C	0.10-0.20
Mn	2.0-3.0
Cr	0.1-0.5
Si	0.2-0.9
Al	0.01-0.5
Si + Al	≥0.1
Si + Al + Cr	≥0.4
Nb	≤0.1
Ti	≤0.1
Mo	≤0.5
Ca	≤0.05
V	≤0.1

balance Fe apart from impurities; and

[0078] b) fulfil at least one of the following conditions:

TS tensile strength (R_m)	900-1100 MPa
YS yield strength ($R_{p0.2}$)	600-800 MPa
YR yield ratio ($R_{p0.2}/R_m$)	≥0.65
bendability (Ri/t)	≤2.5
HER	≥20.

EXAMPLES

[0079] In FIG. **1** the limiting bending radiuses (Ri) divided by the cold rolling thickness has been plotted against the tensile strengths divided by the yield ratios, TS/YR, for the steels in Example 1-4. The inventive steels came within an area defined by the coordinates A, B, C, D when Ri/t (y-axle) is plotted vs TS/YR (x-axle), where A is [1200, 2), B is [2000, 4], C is [2000, 3], and D is [1200, 1]. The upper dotted line can be mathematically expressed as y=0.0025*x−1 and the lower dotted line can be expressed as y=0.0025*x−2.

[0080] Hence, the reference steels that were coiled at a higher temperature are all above the upper dotted line mathematically defined by:

$y=0.0025*x-1$, where y is Ri/t and x is TS(MPa)/YR.

[0081] The inventive steels of example 1-5 are all below the upper line.

[0082] The lower dotted line is defined by

$y=0.0025*x-2$, where y is Ri/t and x is TS(MPa)/YR.

The inventive steels of example 1-5 are all above the lower line.

[0083] Within these borders a good bending property in relation to strength and toughness is achieved.

Example 1

[0084] Steels I1-I6, and reference steels R1 and R2 were produced by conventional metallurgy by converter melting and secondary metallurgy. The compositions are shown in table 1, further elements were present only as impurities, and below the lowest levels specified in the present description. All steels having about the same composition.

TABLE 1

Steel	C	N	Mn	Cr	Si	A
I1	0.105	0.0037	2.63	0.195	0.81	0.045
I2	0.106	0.0038	2.67	0.197	0.84	0.048
I3	0.106	0.0038	2.67	0.197	0.84	0.048
I4	0.105	0.0037	2.63	0.195	0.81	0.045
I5	0.118	0.0028	2.77	0.17	0.94	0.051
I6	0.118	0.0028	2.77	0.17	0.94	0.051
R1	0.112	0.0041	2.7	0.169	0.93	0.046
R2	0.107	0.0051	2.63	0.199	0.85	0.041

[0085] The steels were continuously cast and cut into slabs.

[0086] The slabs were reheated and hot rolled in austenitic range to a thickness of about 2.8 mm. The hot rolling finishing temperature was about 900° C.

[0087] The hot rolled steel strips where thereafter coiled, steel I1-I6 at a coiling temperature of 530° C. and the reference steels R1 and R2 at about 630° C.

[0088] The coiled hot rolled strips were pickled and batch annealed at about 624° C. for 10 hours in order to reduce the tensile strength of the hot rolled strip and thereby reducing the cold rolling forces.

[0089] The strips were thereafter cold rolled in a five stand cold rolling mill to a final thickness of about 1.41 mm and finally subjected to continuous annealing in a Continuous Annealing Line (CAL). In the CAL the strips were heated to a soaking temp of about 850° C. and held there for about 120 s. After annealing, the strips were slow jet cooled to about 750° C. (SJC), and then rapid jet cooled to a holding temperature of about 400° C. (RJC). The strips were hold at about 180 s and then cooled to room temperature.

[0090] A_{c3} was around 800° C. for all steels and the soaking was therefore performed well above A_{c3} as defined by the formula $A_{c3}=910-203*C^{1/2}-15.2\ Ni-30\ Mn+44.7\ Si+104\ V+31.5\ Mo+13.1\ W$.

[0091] The process parameters are shown in table 2.

TABLE 2

	Hot rolling		Batch anneal	Cold rolling		CAL Soaking		
Steel	t (mm)	temp (° C.)	temp (° C.)	t (mm)	red (%)	temp (° C.)	SJC (° C.)	RJC (° C.)
I1	2.8	530	623	1.41	50	850	750	393
I2	2.8	530	623	1.41	40	850	750	397
I3	2.8	530	625	1.41	49	846	750	397
I4	2.8	530	623	1.41	49	842	750	394
I5	2.8	530	624	1.42	49	847	750	391

TABLE 2-continued

	Hot rolling		Batch anneal	Cold rolling		CAL Soaking		
Steel	t (mm)	temp (° C.)	temp (° C.)	t (mm)	red (%)	temp (° C.)	SJC (° C.)	RJC (° C.)
I6	2.8	530	624	1.41	50	846	750	386
R1	2.7	630	624	1.38	50	850	700	415
R2	2.8	627	624	1.4	50	851	750	387

[0092] Yield strength YS and tensile strength TS were derived according to the European norm EN 10002 Part 1. The samples were taken in the longitudinal direction of the strip.

[0093] Samples of the produced strips were subjected to V bend test in accordance with JIS Z2248 to find out the limiting bending radius (Ri). The samples were examined both by eye and under optical microscope with 25 times magnification in order to investigate the occurrence of cracks. Ri/t was determined by dividing the limiting bending radius (Ri) with the thickness of the cold rolled strip (t). Ri is the largest radius in which the material shows no cracks after three bending tests.

[0094] The limiting bending radius (Ri) of the steels I1-I6 that were coiled at 530° C. were less than those R1, R2 that were coiled at 630° C.

[0095] Steel I1-I6 all fulfilled the condition $1 \le 0.0025*TS/YR-Ri/t \le 2$, whereas R1 and R2 fell short.

[0096] The mechanical properties are shown in table 3.

TABLE 3

Steel	YS $R_{p0.2}$	TS R_m	YR $R_{p0.2}/R_m$	Unif. El JIS	Total El JIS (A50)	Ri	Ri/t	0.0025*TS/ YR − Ri/t
I1	838	1038	0.81	8.1	13.4	2.0	1.4	1.80
I2	806	1018	0.79	8.1	13.2	2.5	1.8	1.44
I3	841	1038	0.81	8.2	14.2	2.5	1.8	1.43
I4	817	1027	0.80	7.8	13.4	2.5	1.8	1.45
I5	863	1084	0.80	8.2	13.5	2.5	1.8	1.64
I6	951	1114	0.85	6.8	11.8	2.0	1.4	1.85
R1	953	1087	0.88	6.8	11.2	3.0	2.2	0.93
R2	947	1092	0.87	6.7	11.6	3.5	2.5	0.65

[0097] FIGS. **2***a* and **2***b* show an examination of inventive steel I6 coiled at 530° C. and FIG. **3***a*-**3***c* show an examination of a reference steel R1 coiled at 630° C. The reference steel R1 showed grain boundary oxidation whereas the inventive steel I6 showed no grain boundary oxidation.

[0098] FIG. **3***c* shows visible cracks on the sample surface of the reference steel R1. These comes from breakouts after pickling and cold rolling. Especially the grain boundary oxides lead to outbreaks around the present grains, which could lead to full grain breakouts. The cracks/outbreaks are decremental for the bending ratio.

[0099] FIG. **2***b* show no visible cracks on the sample surface of the inventive steel. The lack of grain boundary oxides and no visible cracks of the inventive steel improves the bending ratio and reduces the risk of liquid metal embrittlement. It further facilitates good phosphatability.

[0100] FIG. **4** show the phosphatation coverage for I6.

[0101] The microstructure of I6 was determined to:

Bainite + Tempered Martensite	>85%
Fresh martensite	about 5%
retained austenite	about 5%

Example 2

[0102] Steel I7 and reference steel R3 were produced by conventional metallurgy by converter melting and secondary metallurgy. The compositions are shown in table 4, further elements were present only as impurities, and below the lowest levels specified in the present description. All steels having about the same composition. The steels I7 and R3 having higher Cr and C contents and lower Si and Mn contents than the steels of example 1. This provides a steel having a higher yield strength and a higher tensile strength.

TABLE 4

Steel	C	N	Mn	Cr	Si	Al
I7	0.223	0.0052	1.49	0.38	0.145	0.044
R3	0.223	0.0052	1.49	0.38	0.145	0.044

[0103] The steels were treated in the same process as Example 1, in which steel I7 was coiled at a coiling temperature of 532° C. and the reference steel R3 at 626° C.

[0104] In the CAL the strips were heated to a soaking temp of about 850° C. and held there for about 120 s. After annealing, the strips were slow jet cooled to about 700° C. (SJC), and then rapid jet cooled to a holding temperature of about 250° C. (RJC). The strips were hold at about 180 s and then cooled to room temperature. All other process parameters were about the same as those of Example 1.

[0105] A_{c3} was around 780° C. for all steels and the soaking was therefore performed well above A_{c3} as defined by the formula $A_{c3}=910-203*C^{1/2}-15.2\ Ni-30\ Mn+44.7\ Si+104\ V+31.5\ Mo+13.1\ W$.

[0106] The process parameters are shown in table 5.

TABLE 5

	Hot rolling		Batch anneal	Cold rolling		CAL Soaking		
Steel	t (mm)	temp (° C.)	temp (° C.)	t (mm)	CR_red (%)	temp (° C.)	SJC (° C.)	RJC (° C.)
I7	2.8	532	625	1.39	0.50	850	700	250
R3	2.8	626	625	1.39	0.50	850	700	250

[0107] Samples of the produced strips were the subjected to the same tests as those of Example 1.

[0108] The limiting bending radius (Ri) of the steel I7 that was coiled at 532° C. was less than that of the steel R3 that was coiled at 626° C.

[0109] Steel I7 fulfilled the condition $1 \le 0.0025*TS/YR-Ri/t \le 2$, whereas R3 fell short.

[0110] The mechanical properties are shown in table 6.

TABLE 6

Steel	YS $R_{p0.2}$	TS R_m	YR $R_{p0.2}/R_m$	Unif. El JIS	Total El JIS (A50)	Ri	Ri/t	0.0025*TS/YR − Ri/t
I7	1181	1522	0.78	3.8	6.5	5.0	3.6	1.31
R3	1221	1489	0.82	3.4	5.9	6.0	4.3	0.22

[0111] The microstructure of I7 was determined to:

Bainite + Tempered martensite	about 95%
retained austenite	about 5%

Example 3

[0112] Steel I8 and reference steel R4 were produced by conventional metallurgy by converter melting and secondary metallurgy. The compositions are shown in table 7, further elements were present only as impurities, and below the lowest levels specified in the present description. All steels having about the same composition. The steels I8 and R4 having higher Si and C contents and lower Cr content than the steels of example 1. This results in a steel having a slightly higher tensile strength than that of example 1.

TABLE 7

Steel	C	N	Mn	Cr	Si	Al
I8	0.198	0.0037	2.51	0.029	1.49	0.054
R4	0.202	0.0053	2.53	0.027	1.45	0.056

[0113] The steels were treated in the same process as Example 1, in which steel I8 was coiled at a coiling temperature of 535° C. and the reference steel R4 at 633° C. All other process parameters were about the same as those of Example 1.

[0114] A_{c3} was around 810-815° C. for the steels and the soaking was therefore performed well above A_{c3} as defined by the formula $A_{c3}=910-203*C^{1/2}-15.2\ Ni-30\ Mn+44.7\ Si+104\ V+31.5\ Mo+13.1\ W$.

[0115] The process parameters are shown in table 8.

TABLE 8

	Hot rolling		Batch anneal	Cold rolling		CAL Soaking		
Steel	t (mm)	temp (° C.)	temp (° C.)	t (mm)	red (%)	temp (° C.)	SJC (° C.)	RJC (° C.)
I8	3.2	535	630	1.19	0.37	850	700	350
R4	3.5	633	630	1.47	0.42	850	700	350

[0116] Samples of the produced strips were the subjected to the same tests as those of Example 1.

[0117] The limiting bending radius (Ri) of the steel I8 that was coiled at 535° C. was less than that of the steel R4 that was coiled at 633° C.

[0118] Steel I8 fulfilled the condition $1 \le 0.0025*TS/YR-Ri/t \le 2$, whereas R4 fell short.

[0119] The mechanical properties are shown in table 9.

TABLE 9

Steel	YS $R_{p0.2}$	TS R_m	YR $R_{p0.2}/R_m$	Unif. El JIS	Total El JIS (A50)	Ri	Ri/t	0.0025*TS/YR − Ri/t
I8	933	1198	0.78	10.0	15.8	3.0	2.5	1.32
R4	864	1212	0.71	10.5	16.5	5.0	3.4	0.85

[0120] The microstructure of I8 was determined to:

Bainite + Tempered Martensite	>70%
Fresh martensite	<15%
retained austenite	<15%

Example 4

[0121] Steel I9 and reference steel R5 were produced by conventional metallurgy by converter melting and secondary metallurgy. The compositions are shown in table 10, further elements were present only as impurities, and below the lowest levels specified in the present description. All steels having about the same composition. The steels I9 and R5 having slightly higher C content and slightly lower Mn and Si content than the steels of example 1.

TABLE 10

Steel	C	N	Mn	Cr	Si	Al
I9	0.155	0.0061	2.33	0.24	0.441	0.053
R5	0.155	0.0061	2.33	0.24	0.441	0.053

[0122] In example 4 the CAL line was replaced by a Hot Dip Galvanizing Line. Prior to the Hot Dip Galvanizing Line the steels were treated in a similar process as Example 1, in which steel I9 was coiled at a coiling temperature of 520° C. and the reference steel R5 at 630° C. The batch annealing temperature was 570° C.

[0123] A_{c3} was around 780° C. for the steels and the soaking was therefore performed well above A_{c3} as defined by the formula A_{c3}=910-203*$C^{1/2}$−15.2 Ni−30 Mn+44.7 Si+104 V+31.5 Mo+13.1 W.

[0124] The process parameters are shown in table 11.

TABLE 11

	Hot rolling		Batch anneal	Cold rolling		Hot Dip Galvanizing Line		
						Soaking		
Steel	t (mm)	temp (° C.)	temp (° C.)	t (mm)	red (%)	temp (° C.)	SJC (° C.)	RJC (° C.)
I9	3.0	520	570	1.4	0.47	850	750	380
R5	3.0	630	570	1.4	0.47	850	750	380

[0125] Samples of the produced strips were the subjected to the same tests as those of Example 1.

[0126] The limiting bending radius (Ri) of the steel I9 that was coiled at 520° C. was less than that of the steel R5 that was coiled at 630° C.

[0127] Steel I9 fulfilled the condition 1≤0.0025*TS/YR−Ri/t≤2, whereas R5 fell short.

[0128] The mechanical properties are shown in table 12.

TABLE 12

Steel	YS $R_{p0.2}$	TS R_m	YR $R_{p0.2}/R_m$	Unif. El JIS	Total El JIS (A50)	Ri	Ri/t	0.0025*TS/YR − Ri/t
I9	727	1000	0.73	9	15.1	3	2.1	1.30
R5	739	1012	0.73	9	15.3	4	2.9	0.61

[0129] The microstructure of I9 was determined to:

Bainite + Tempered Martensite	about 85%
Fresh martensite	about 5%
retained austenite	about 10%

1. A cold rolled steel strip or sheet

a) having a composition consisting of in wt. %:

C	0.08-0.28
Mn	1.4-4.5
Cr	0.01-0.5
Si	0.01-2.5
Al	0.01-0.6
Si + Al	≥0.1
Si + Al + Cr	≥0.4
Nb	≤0.1
Ti	≤0.1
Mo	≤0.5
Ca	≤0.05
V	≤0.1
Cu	≤0.06%
Ni	≤0.08%
B	≤0.0006%
P	≤0.02%
S	≤0.005%
As	≤0.010%
Zr	≤0.006%
Sn	≤0.015%
O	≤0.0003
H	≤0.0020
N	≤0.015%

balance Fe apart from impurities;

b) fulfilling the following conditions:

TS tensile strength (R_m)	950-1550 MPa
YS yield strength ($R_{p0.2}$)	550-1400 MPa
YR yield ratio ($R_{p0.2}/R_m$)	≥0.50
bendability (Ri/t)	≤5;

c) being within the area defined by the coordinates A, B, C, D, where Ri/t y-axle is plotted vs TS(MPa)/YR x-axle, and where A is [1200, 2), B is [2000, 4], C is [2000, 3], and D is [1200, 1];

d) having a multiphase microstructure comprising in vol %

tempered martensite + bainite	≥50
fresh martensite	≤10
retained austenite	2-20
polygonal ferrite	≤1;

e) wherein the amount of retained austenite was measured by means of the saturation magnetization method described in detail in Proc. Int. Conf. on TRIP-aided high strength ferrous alloys (2002), Ghent, Belgium, p. 61-64;

f) wherein the bendability Ri/t is determined in accordance with JIS Z2248, where Ri is the limiting bending radius and t is the sheet thickness;

g) wherein the yield strength and tensile strength are determined according to the European norm EN 10002 Part 1; and

h) the steel does not contain other kind of ferrite than polygonal ferrite

2. The cold roll strip or sheet according to claim **1**, wherein the composition comprising in wt %:

C	0.1-0.25
Mn	1.4-3
Cr	0.01-0.5
Si	0.1-1
Al	0.01-0.1
Si + Al	≥0.1
Si + Al + Cr	≥0.4
Nb	≤0.008
Ti	≤0.02
Mo	≤0.08
Ca	≤0.005
V	≤0.02

balance Fe apart from impurities.

3. The cold roll strip or sheet according to claim **1** wherein the composition fulfilling at least one of the following requirements:

Si	≥0.4
Si + Al	≥0.8
Al	≤0.1
Mn + Cr	1.7-5.0.

4. The cold roll strip or sheet according to claim **3** fulfilling all of the requirements.

5. The cold roll strip or sheet according to claim **1** wherein the microstructure fulfils at least one of the following requirements:

tempered martensite + bainite	≥60
fresh martensite	1-10
retained austenite	5-15.

6. The cold roll strip or sheet according to claim **1**, wherein the yield ratio is ≥0.70.

7. The cold roll strip or sheet according to claim **1**,

a) having a composition comprising of in wt. %:

C	0.08-0.16
Mn	2.0-3.0
Cr	0.1-0.5
Si	0.5-1.2
Al	0.01-0.5
Si + Al	≥0.1
Si + Al + Cr	≥0.4
Nb	≤0.1
Ti	≤0.1
Mo	≤0.5
Ca	≤0.05
V	≤0.1

balance Fe apart from impurities; and

a) fulfilling at least one of the following conditions:

TS tensile strength (R_m)	950-1150 MPa
YS yield strength ($R_{p0.2}$)	750-1000 MPa
YR yield ratio ($R_{p0.2}/R_m$)	≥0.70
bendability (Ri/t)	≤2.

8. The cold roll strip or sheet according to claim **1**,

a) having a composition comprising of in wt. %:

C	0.15-0.25
Mn	1.0-2.0
Cr	0.1-0.5
Si	0.1-0.5
Al	0.01-0.5
Si + Al	≥0.1
Si + Al + Cr	≥0.4
Nb	≤0.1
Ti	≤0.1
Mo	≤0.5
Ca	≤0.05
V	≤0.1

balance Fe apart from impurities; and

b) fulfilling at least one of the following conditions:

TS tensile strength (R_m)	1300-1550 MPa
YS yield strength ($R_{p0.2}$)	1000-1300 MPa
YR yield ratio ($R_{p0.2}/R_m$)	≥0.70
bendability (Ri/t)	≤4.

9. The cold roll strip or sheet according to claim **1**,

a) having a composition comprising of in wt. %:

C	0.15-0.25
Mn	2.0-3.0
Cr	0.1-0.5
Si	1-2.0
Al	0.01-0.5
Si + Al	≥0.1
Si + Al + Cr	≥0.4
Nb	≤0.1
Ti	≤0.1
Mo	≤0.5
Ca	≤0.05
V	≤0.1

balance Fe apart from impurities; and

b) fulfilling at least one of the following conditions:

TS tensile strength (R_m)	1100-1300 MPa
YS yield strength ($R_{p0.2}$)	900-1100 MPa
YR yield ratio ($R_{p0.2}/R_m$)	≥0.70
bendability (Ri/t)	≤3.

10. The cold roll strip or sheet according to claim **1**,

a) having a composition comprising of in wt. %:

C	0.10-0.20
Mn	2.0-3.0
Cr	0.1-0.5
Si	0.2-0.9
Al	0.01-0.5
Si + Al	≥0.1
Si + Al + Cr	≥0.4
Nb	≤0.1
Ti	≤0.1
Mo	≤0.5
Ca	≤0.05
V	≤0.1

balance Fe apart from impurities; and

b) fulfilling at least one of the following conditions:

TS tensile strength (R_m)	900-1100 MPa
YS yield strength ($R_{p0.2}$)	600-800 MPa
YR yield ratio ($R_{p0.2}/R_m$)	≥0.65
bendability (Ri/t)	≤2.5.

11. The cold roll strip or sheet according to claim **1**, wherein

Al≤0.1.

12. A method of manufacturing of a cold rolled steel strip or sheet according to claim **1**, comprising the following steps:

a) providing a steel slab;

b) hot rolling the slab in the austenitic range to a hot rolled strip, wherein the hot rolling finishing temperature is greater than or equal to 850° C.;

c) coiling the hot rolled strip at a coiling temperature in the range of 500-540° C.;

d) optionally performing scale removal process on the coiled steel strip;

e) batch annealing the coiled strip at a temperature in the range of 500-650° C. for a duration of 5-30 h;

f) cold rolling the annealed steel strip with a reduction rate between 35 and 90%;

g) further treating the cold rolled steel strip in a Continuously Annealing Line or in a Hot Dip Galvanizing Line, in which the soaking temperature is 800-1000° C., and a holding temperature is 200-500° C. for a time of 150 to 1000 s; and

h) further cooling the steel strip down to room temperature.

13. The method according to claim **12**, fulfilling at least one of the following conditions:

in step b) reheating the slab to a temperature between 1000° C. and 1280° C.;

in step e) batch annealing in the range of 550-650° C.; and

in step g) the holding temperature is 350-450° C.

14. The method according to claim **12**, wherein the soaking temperature in step g) is in the range of 830-900° C.

15. The method according to claim **12**, wherein the soaking temperature in step g) is above A_{c3} as defined by: A_{c3}=910-203*$C^{1/2}$−15.2 Ni−30 Mn+44.7 Si+104 V+31.5 Mo+13.1 W.

16. The method according claim **15**, wherein the soaking temperature in step g) is above A_{c3}+20° C.

17. The method according claim **15**, wherein the soaking temperature in step g) is above A_{c3}+30° C.

* * * * *