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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
7 January 2016 (07.01.2016)

WIPO | PCT

(10) International Publication Number
WO 2016/001703 A1

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

(21) **International Application Number**:
PCT/IB2014/002285

(22) **International Filing Date**:
3 July 2014 (03.07.2014)

(25) **Filing Language**: English

(26) **Publication Language**: English

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(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, 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, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, 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).

Published:

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

WO 2016/001703 A1

(54) **Title**: METHOD FOR MANUFACTURING A HIGH STRENGTH STEEL SHEET AND SHEET OBTAINED BY THE METHOD

(57) **Abstract**: A method for manufacturing a high-strength steel sheet having a tensile strength of more than 1100 MPa and a yield strength of more than 700 MPa, made of a steel containing in percent by weight: 0.1 % ≤ C ≤ 0.35%, 4.5% ≤ Mn ≤ 10%, 1% ≤ Si ≤ 3%, 0.03% ≤ Al ≤ 2.5%, the remainder being Fe and impurities resulting from the smelting, the method comprising the steps of annealing a rolled sheet made of said steel by soaking it at an annealing temperature TA higher than the Ac-i transformation point of the steel but less than 1000°C, cooling the annealed sheet to a quenching temperature QT less than 450°C, maintaining the steel sheet at an overaging temperature PT between 350°C and 500°C for an overaging time Pt of more than 5 s cooling the sheet down to the ambient temperature. Sheet obtained.

METHOD FOR MANUFACTURING A HIGH STRENGTH STEEL SHEET AND SHEET OBTAINED BY THE METHOD

The present invention is related to a method for manufacturing a high-strength steel sheet using a continuous heat treatment line and to the sheet obtained by this method.

To produce various equipments such as trailers, trucks, agricultural machines, automotive parts and so on, high strength steel sheets made of DP (dual phase) or TRIP (transformation induced plasticity) steels are used. Some of such steels which are produced on continuous annealing lines, containing for example about 0.2% C, about 2% Mn and about 1.7% Si, have a tensile strength of about 980 MPa.

In order to reduce the weight of the equipments made of these steels, which is very desirable to improve their energy efficiency, it was proposed to use CMnSi steels containing 0.1% to 0.4% C, 2% to 4% Mn, up to 2% Si or Si+Al, such steels being heat treated in order to have a martensitic structure with a significant content of retained austenite or a ferrito-martensitic structure. Such steels are used to produce grades having a tensile strength of more than 1000 MPa. These sheets are produced on continuous annealing lines and are optionally hot dip coated. The mechanical properties of the sheets depend on the amount of residual austenite which has to be sufficiently high. This requires that the austenite is sufficiently stable. Moreover, in order to perform the treatment on existing lines with a good productivity, it is desirable that the characteristic transformation points of the steel such as Ac_1, Ac_3, Ms and Mf are not too restrictive.

For these reasons, it remains the need to have a steel and a process to manufacture easily high strength steel sheets on continuous heat treatment lines.

For this purpose the invention relates to a method for manufacturing a high-strength steel sheet having a tensile strength of more than 1100 MPa and a yield strength of more than 700 MPa, made of a steel containing in percent by weight:

$$0.1\% \leq C \leq 0.35\%$$

$$4.5\% \leq Mn \leq 10\%$$

$$1\% \leq Si \leq 3\%$$

$$0.03 \leq Al \leq 2.5\%$$

the remainder being Fe and impurities resulting from the smelting, the method comprising the steps of:

- annealing a rolled sheet made of said steel by soaking it at an annealing temperature TA higher than the Ac_1 transformation point of the steel but less than 1000°C,
- cooling the annealed sheet to a quenching temperature QT less than 450°C,

- maintaining the steel sheet at an overaging temperature PT between 350°C and 500°C for an overaging time Pt of more than 5 s and less than 600 s,
- cooling the sheet down to the ambient temperature.

The quenching temperature QT is less than the Ms transformation point of the steel and the cooling is made at a cooling speed sufficient to obtain a structure containing martensite.

In a preferable embodiment, the annealing temperature TA is higher than the Ac_3 transformation point of the steel, and the quenching temperature QT is such that the structure of the steel contains at least 20% of retained austenite and at least 65% of martensite.

Preferably, the chemical composition of the steel is such that:

$$0.15\% \leq C \leq 0.25\%$$

$$4.5\% \leq Mn \leq 5.5\%$$

$$1.4\% \leq Si \leq 1.8\%$$

$$0.03 \leq Al \leq 2.5\%$$

the annealing temperature AT is higher than 760°C, the quenching temperature QT is less than 170°C and the structure of the steel contains between 20% and 30% of retained austenite.

In a particular embodiment, the quenching temperature can also be less than 150°C.

In one embodiment, the overaging temperature PT is between 380°C and 470°C and the sheet is maintained at the overaging temperature for a time Pt between 90 s and 550 s.

In one embodiment, the overaging temperature PT is between 440°C and 470°C and the sheet is maintained at the overaging temperature for a time Pt between 5 s and 15 s. In this case, the holding at the overaging temperature can be made by passing the sheet in a hot dip coating bath. After passing in hot a dip coating bath, the sheet can be further maintained at a temperature between 480°C and 570°C for the galvannealing before being cooled down to the ambient temperature.

In one embodiment, the chemical composition of the steel is such that:

$$0.15\% \leq C \leq 0.25\%$$

$$6.5\% \leq Mn \leq 7.5\%$$

$$1.4\% \leq Si \leq 1.8\%$$

$$0.03 \leq Al \leq 2.5\%$$

the annealing temperature AT is higher than 710°C, the quenching temperature QT is between 120°C and 180°C, the overaging temperature PT is between 350°C and 450°C and the overaging time Pt is between 50 s and 600 s.

In another embodiment, the chemical composition is such that:

$0.25\% \leq C \leq 0.35\%$

$4.5\% \leq Mn \leq 5.5\%$

$1.4\% \leq Si \leq 1.8\%$

$0.03 \leq Al \leq 2.5\%$

and the annealing temperature is higher than 750°C, the quenching temperature QT is between 100°C and 160°C, the overaging temperature PT is between 350°C and 450°C and the overaging time Pt is between 90 s and 600 s.

In a particular embodiment, the chemical composition of the steel is such that:

$0.15\% \leq C \leq 0.25\%$

$4.5\% \leq Mn \leq 5.5\%$

$1.4\% \leq Si \leq 1.8\%$

$0.03 \leq Al \leq 2.5\%$

and the annealing temperature AT is less than the Ac_3 transformation point of the steel, the quenching temperature QT is between 110°C and 170°C, the overaging temperature AT is between 350°C and 450°C, the overaging time Pt is between 90 s and 600 s, the structure of the steel containing at least 10% of ferrite, at least 50% of martensite and at least 15% of retained austenite.

The annealing, the quenching and the overaging are made on a continuous heat treatment line such as a continuous annealing line.

The preparation of the sheet by rolling can comprise hot rolling of a slab and optionally cold rolling.

The invention is also related to a high-strength steel sheet having a tensile strength of more than 1100 MPa and a yield strength of more than 700 MPa the chemical composition of the steel containing, in weight percent:

$0.1\% \leq C \leq 0.35\%$

$4.5\% \leq Mn \leq 10\%$

$1\% \; Si \leq 3\%$

$0.03 \leq Al \leq 2.5\%$

the remainder being Fe and impurities resulting from the smelting.

In a preferable embodiment, the structure of the steel contains at least 20% of retained austenite, at least 65% of martensite and less than 10% of the sum of ferrite and bainite.

The chemical composition of the steel is preferably such that:

$0.15\% \leq C \leq 0.25\%$

$4.5\% \leq Mn \leq 5.5\ \%$

$1.4\% \leq Si \leq 1.8\%$

$0.03 \leq Al \leq 2.5\%$

Then, the yield strength YS can be higher than 1100 MPa, the tensile strength TS higher than 1350 MPa, the uniform elongation UE can be of more than 10% and the total elongation TE of more than 12%.

In one embodiment, the chemical composition of the steel is such that:

$0.15\% \leq C \leq 0.25\%$

$6.5\% \leq Mn \leq 7.5\ \%$

$1.4\% \leq Si \leq 1.8\%$

$0.03 \leq Al \leq 2.5\%$

and the yield strength YS is higher than 1000 MPa and the tensile strength TS is higher than 1100 MPa.

In another embodiment, the chemical composition of the steel is such that:

$0.25\% \leq C \leq 0.35\%$

$4.5\% \leq Mn \leq 5.5\%$

$1.4\% \leq Si \leq 1.8\%$

$0.03 \leq Al \leq 2.5\%$

and the yield strength YS is higher than 900 MPa and the tensile strength TS is higher than 1250 MPa.

In a particular embodiment, the chemical composition of the steel is such that:

$0.15\% \leq C \leq 0.25\%$

$4.5\% \leq Mn \leq 5.5\%$

$1.4\% \leq Si \leq 1.8\%$

$0.03 \leq Al \leq 2.5\%$

and the structure of the steel comprises at least 15% of ferrite, at least 50% of martensite and at least 15% of retained austenite.

In any case, at least one of the faces of the sheet may comprise a metallic coating or an alloyed metallic coating such as zinc coating or alloyed zinc coating.

The invention will now be described in details and illustrated by examples without introducing limitations.

The steel which is used to manufacture high-strength steel sheets according to the present invention has the following composition:

- $0.1\% \leq C \leq 0.35\%$ for ensuring a satisfactory strength and improving the stability of the austenite. Preferably, the carbon content is higher than 0.15%, it is also preferably less than 0.25%, but in a particular embodiment it can be higher than 0.25%.

- 4.5% ≤ Mn ≤ 10%. The manganese content must be higher than 4.5% in order to improve the stability of the retained austenite by higher chemical enrichment of austenite in manganese and decreasing the grain size of austenite. It is expected that the decreasing of the austenite grain size will reduce the diffusion distance and therefore foster the diffusion of C and Mn during the overaging step. Moreover, manganese contents higher than 4.5% decrease the Ms transformation point, the Ac_1 and Ac_3 transformation points which makes easier the achievement of heat treatment. For example, when the Ac_3 point is lowered, the annealing temperature can be reduced, which makes easier the heating i.e. it is possible to reduce the heating power or to increase the speed of passage of the sheet. But, the manganese content must remain less than 10% in order not to decrease too much the ductility and weldability. Preferably, the manganese content is less than 7.5%, and preferably less than 5.5%. But, in a particular embodiment it is higher than 6.5%. It must be noted that adding Al increases Ac_3 and counter balances the Mn effect, such addition is not detrimental up to 2.5% of Al.

- 1% ≤ Si ≤ 3% and preferably Si ≥ 1.4% in order to stabilize the austenite, to provide solid solution strengthening and to delay the formation of carbides during carbon redistribution from martensite to austenite resulting from the overaging. But at a too high content, silicon oxides will form at the surface which is detrimental to coatability. Thus the silicon content is preferably less than or equal to 1.8%.

- 0.03% ≤ Al ≤ 2.5%. Al is added to deoxidize the liquid steel and it increases robustness meaning that the evolution of austenite fraction is less sensible to annealing temperature. The minimum Al content is 0.03%. At high content, aluminum delays the formation of carbides during carbon redistribution from martensite to austenite resulting from the overaging. To delay the formation of carbides the minimum content of Al+Si should be 1.4%. The maximum of Al is 2.5%, above such an amount, delta ferrite is formed at high temperature. Delta ferrite is detrimental to weldability and is a brittle phase. It must be noted that Al increases significantly the Ac_3 transformation point which renders the annealing more difficult; such effect is counter balanced by the presence of high Mn contents

The remainder is Fe and impurities resulting from the smelting. Such impurities include N, S, P, and residual elements such as Cr, Ni, Mo, Cu, and B.

Usually, the N content remains less than 0.01%, the S content less than 0.01%, the P content less than 0.02 %, the Cr content less than 0.1%, the Ni content less than 0.1%, the Mo content less than 0.05%, the Cu content less than 0.2% and the B content less than 0.0010%. Micro alloying with Nb, Ti and V is possible in this concept but Ti content must be less than 0.1%, the Nb content less than 0.1%, and the V content less than 0.3%

With such steel, hot rolled sheets are produced. These hot rolled sheets have a thickness between 2 mm and 5 mm, for example.

Optionally, the hot rolled sheets are cold rolled in order to obtain cold rolled sheets having a thickness between 0.5 mm and 2 mm, for example. Those who are skilled in the art know how to produce such hot or cold sheets.

Then the hot or cold rolled sheets are heat treated on a continuous heat treatment line such as continuous annealing line comprising at least a heating zone able to heat the sheet up to an annealing temperature, a soaking zone able to maintain the sheet at the annealing temperature or around this temperature, a cooling zone able to rapidly cool the sheet down to a quenching temperature QT, a reheating zone able to heat the sheet up to an overaging temperature PT and an overaging zone able to maintain the sheet at the overaging temperature or around this temperature for a time Pt. Optionally, the overaging zone can be a hot dip coating zone comprising at least a hot dip coating bath containing a liquid metal such as zinc and optionally an alloying zone.

Such continuous heat treatment line is known to those skilled in the art.

The purpose of the heat treatment is to confer to the steel a structure suitable to obtain the desired characteristics of strength and ductility and, possibly, to hot dip the sheet.

In any case, the annealing temperature AT is higher than the Ac_1 transformation point of the steel in order to form enough austenite able to be transformed by quenching and overaging. It must be noted that contents of microstructural elements are given as a surface fraction based on optical and scanning microscope pictures.

If the structure of the sheet before annealing contains ferrite and pearlite and if a significant content of ferrite is desired after quenching and overaging, the annealing temperature must remain less than the Ac_3 transformation point of the steel.

If it is desired that the structure before quenching is completely austenitic, the annealing temperature AT must be higher than the Ac_3 transformation point of the steel, but it is preferable that it remains less than 1000°C in order not to coarsen too much the austenitic grains.

In any case, it is preferable to maintain the sheet at that annealing temperature at least 60 s but more than 200 s is not necessary.

It is desired that during quenching and overaging, the austenite which is formed during the annealing step is transformed at least partially in martensite. The quenching temperature QT must be less than the Ms transformation point of the steel. As it is preferably desired to have a structure containing a significant content of retained austenite, the QT temperature must not be too low and must be chosen according to the

desired content of retained austenite. More specifically, it is possible to determine for each chemical composition of the steel an optimal quenching temperature QTop that theoretically achieves an optimum residual austenite content. This optimum quenching temperature can be calculated using the Andrews and Koisten Marburger relationships:

$Ms = 539 – 423 \times C – 30.4 \times Mn – 12.1 \times Cr – 7.5 \times Mo - 7.5 \times Si$

and

$f\alpha' = 1 – \exp\{0.0011 \times (Ms-T)\}$

$f\alpha'$ being the proportion of martensite at the temperature T during quenching,

and by assuming that, after quenching down to a temperature QT the steel is overaged at a temperature higher than QT and that due to the overaging, the partitioning of carbon between the martensite and the remaining austenite is completely realized.

Those which are skilled in the art know how to make this calculation.

The optimal quenching temperature QTop is not necessarily the quenching temperature QT which is chosen to make actual heat treatments. Preferably, the quenching temperature QT is chosen equal or near to this optimal quenching temperature. With the steel according to the present invention, the maximum residual austenite content which is possible to obtain after a full austenitization is between 20% and 30%. As during overaging or after it, some of the residual austenite can be transformed in bainite or in fresh martensite, the structure which is obtained after a full austenitization contains some ferrite or some bainite, the total content of such constituents is less than 10% and preferably less than 5%. With the steel according to the present invention, when the quenching temperature QT is less than 100°C, the structure could be full martensitic.

When the austenitization is not full i.e. when the annealing temperature is between the Ac_1 transformation point and the Ac_3 transformation point of the steel, the content of austenite and martensite depends on the content of ferrite after annealing i.e. depending on the annealing temperature. But, preferably, the ferrite content is between 10% and 40%, more preferably higher than 15% and more preferably less than 35%, the martensite content is at least 50% and the retained austenite content is at least 10% and preferably at least 15%.

When the structure contains martensite and retained austenite, the purpose of the overaging is generally to transfer carbon from the martensite to the retained austenite in order to improve the ductility of the martensite and to increase the carbon content of the austenite in order to render possible a TRIP effect, without forming significant amount of bainite and/or of carbides. For this, the overaging temperature PT must be between 350°C and 500°C and the overaging time Pt must be preferably of more than 90 s in order that the enrichment of the austenite in carbon is enough. But this time must not be too long

and preferably must be less than 600 s in order to have no or about no decomposition of the austenite in a structure like bainite. In any case, the overaging temperature PT has to be chosen sufficiently high given the overaging time Pt which depends on the characteristics of the annealing line and on the thickness of the sheet, in order to have enough transfer of carbon from martensite to austenite i.e. enough partitioning.

For this purpose, if T (t) is the actual temperature of the sheet at the time t, during the overaging, in order to have enough partitioning, the conditions of the overaging have to be such that:

$$\int_{to}^{t_1} D[T(t)]dt \geq K \min \qquad (1)$$

With:

t_0 = starting time of the overaging,

t_1 = end time of the overaging,

D[T] = Do exp(-Q/RT), T being the temperature in Kelvin,

Do = 3.72 x 10^{-5} m^2/s,

Q = 148 kJ/mol

R = 8,314 J (mol.K)

If the overaging is made at a constant temperature PT during a time Pt and if the heating at the beginning of the overaging and the cooling at the end are not considered, the condition (1) become:

Do exp (-Q/R.PT) x Pt ≥ Kmin.

Kmin is a value that those who are skilled in the art can determine.

In a particular embodiment, the overaging temperature PT is equal to the optimal temperature for hot dip coating i.e. between 440°C and 470°C and typically about 460°C. Moreover, the overaging can be made at least partially by the passage of the sheet in the hot dip coating bath. In this case, the overaging temperature is between 5 s and 60 s. If the layer of coating is alloyed by heating and maintaining at a temperature between 480°C and 570°C for the galvannealing, this treatment will contribute to the overaging of the steel.

More precisely, with a steel having the following composition: 0.15% ≤ C ≤ 0.25%, 4.5% ≤ Mn ≤ 5.5%, 1.4% ≤ Si ≤ 1.8%, 0.03 ≤ Al ≤ 2.5%, the reminder being Fe and impurities, it is possible to obtain high strength steel sheet having a yield strength YS higher than 1100 MPa, a tensile strength TS higher than 1350 MPa, a uniform elongation UE of more than 10% and a total elongation TE of more than 12%. These properties can be obtained if the structure is essentially martensitic with a significant content of retained

austenite, preferably containing more than 65% of martensite and more than 20% of retained austenite, the sum of the ferrite and bainite contents remaining less than 10%.

The sheet can be coated or not. When it is coated, it can be galvanized or galvannealed.

To obtain such steel, it is necessary to anneal the sheet at a temperature higher than the Ac_3 transformation point of the steel and to quench it down to a temperature less than the Ms transformation point followed by a reheating to the overaging temperature.

Regarding the Ac_3 transformation point, it can be noted that for this steel, it is less than about 750°C while it is about 850°C for the steels generally used to produce sheets of such category. This difference of about 100°C is very important because it is easier to heat a sheet up to a temperature that must only be higher than 750°C than to a temperature that must be higher than 850°C. Heating needs less energy and may be faster. Thus it is possible to have a better productivity, at the same time, the Ac_1 and Ac_3 points must not be too close because if they are too close, the steel robustness will be impaired since a small annealing temperature change will induce a large modification of phase fractions and consequently unstable mechanical properties.

With this steel, it is also possible to obtain sheets having a structure containing at least 50% of martensite, at least 10% and preferably at least 15% of retained austenite and at least 10% and preferably at least 15% of ferrite. For this, the annealing temperature must be between the Ac_1 and Ac_3 transformation points and the quenching temperature must be less than the Ms transformation point. The yield strength can be higher than 1300 MPa and the total elongation can be of about 14% which is very good for the formability of the sheet. But, the yield strength is only about 750 MPa.

With a steel containing 0.15% to 0.25% C, 6.5% to 7.5% Mn, 1.4% to 1.8% Si, less $0.03 \leq Al \leq 2.5\%$ the reminder being Fe and impurities, it is possible to obtain a yield strength higher than 1000 MPa and a tensile strength higher than 1100 MPa with a structure consisting of martensite and retained austenite. Due to the high Mn content, the Ac_3, Ac_1 and Ms transformation points of this steel are significantly lowered: Ac_3 is less than 700°C, Ac_1 less than 450°C and Ms less than 250°C which is useful since heat treatments are easier to realize, i.e. faster annealing and less energy consuming annealing treatments are possible.

With a steel containing 0.25% to 0.35% C, 4.5% to 5.5% Mn, 1.4% to 1.8% Si, 0.03% to 2.5% Al, the reminder being Fe and impurities, having a structure consisting of martensite and retained austenite, it is possible to obtain on the sheet a yield strength higher than 900 MPa and a tensile strength higher than 1250 MPa.

Sheets made of steels having the compositions which are reported in table I were produced by hot rolling, the hot rolled sheets having a thickness of 2.4 mm. The hot rolled sheets were batch annealed at 600°C for 5 hours, then pickled and cold rolled to obtain sheets having a thickness of 1.2 mm. Then, these sheets were heat treated.

Before heat treatment, an optimal quenching temperature QTop was determined for each composition. This optimal quenching temperature is the temperature at which the quenching has theoretically to be stopped in order to obtain the maximum austenite content in the structure after heat treatment. But, it is not necessarily the QT temperature that is preferable to choose for the actual heat treatment.

Each heat treatment included an annealing at an annealing temperature AT, a quenching down to a quenching temperature QT, an overaging at an overaging temperature PT during an overaging time Pt. The structures and the mechanical properties YS, TS, UE and TE were measured.

The values of the Ac_1, Ac_3 and Ms transformation points of the steels and the optimal quenching temperature QTop are reported in Table I. The conditions, the structures and the mechanical properties resulting from the treatment are reported in table II.

Table I

Cast	C %	Mn %	Si %	Al %	Ac_1 °C	Ac_3 °C	Ms °C	Mf °C	QTop °C
H166	0.2	5	1.6	0.03	562	742	284	104	160
H167	0.2	5	1.6	1.5	592	891	284	104	160
H240	0.2	7	1.6	0.03	434	696	224	38	110
H169	0.3	5	1.6	0.03	585	727	242	37	155
H170	0.2	5	-	0.03	512	718	302	104	170

In this table, cast H166, H167, H240 and H169 are examples of the invention. The cast, H170 is out of the scope of the invention and is given as comparison.

Table II

Test	Cast	AT °C	QT °C	PT °C	Pt s	Structure	YS MPa	TS MPa	UE %	TE %
1	H166	800	160	400	500	M+27% A	1030	1410	11	14
2	H166	800	140	400	500	M+23% A	1140	1400	11	13
3	H166	800	180	400	500	M+29% A	940	1410	7	8
4	H166	800	160	400	100	M+27% A	990	1450	10	13
5	H166	730	160	400	500	F+M+17% A	-	-	-	-
6	H166	800	160	450	500	M+27% A	950	1470	9.5	12
7	H166	800	160	450	10	M+29% A	1030	1400	9	9
8	H166	700	120	400	500	F+M+45% A	750	1347	14	-
9	H166	800	400	400	5400	M (< 2% A)	1050	1773	2	4
10	H167	1050	160	400	500	-	1000	1200	5	11
11	H167	1050	140	400	500	-	1000	1200	3	8
12	H167	1050	180	400	500	-	-	-	-	-
13	H167	1050	160	400	100	-	-	-	-	-
14	H240	800	130	400	500	-	1180	1260	1	1
15	H240	800	150	400	500	-	1090	1190	1.5	1.5
16	H240	800	170	400	500	-	900	1140	2	2
17	H169	800	110	400	500	-	1100	1400	4	4
18	H169	800	130	400	500	-	950	1180	2.5	2.5
19	H169	800	150	400	500	-	790	1210	2	2
20	H170	800	130	400	500	-	1020	1270	6	8
21	H170	800	150	400	500	-	960	1290	6	9
22	H170	800	170	400	500	-	950	1300	5	8

The examples 1 to 9 according to the invention are related to a steel containing 0.15% to 0.25% C, 4.5% to 5.5% Mn, 1.4% to 1.8% Si and $0.03 \leq Al \leq 2.5\%$. For the examples 5 and 8, the annealing is intercritical. Example 2 shows that with an annealing above Ac_3, a quenching temperature a little lower than the optional quenching temperature and an overaging at 400°C during 500 s, it is possible to obtain a yield stress

higher than 1100 MPa, a tensile strength higher than 1350 MPa, a uniform elongation higher than 10% and a tensile strength higher than 12%. The examples 1, 3, 4, 6 show that with higher quenching temperatures the yield strength is slightly degraded.

The example 8 shows that with an intercritical annealing, it is possible to obtain a high tensile strength with a very good uniform elongation. But, the yield strength is not very high.

The example 9 shows that with a full martensitic structure, it is possible to obtain a high yield strength and a very high tensile strength. But, the elongations are not very high. The reason is that the high Mn content keeps bainite from forming at 400°C even after 5400 s.

The examples 10 to 13 which are related to a steel containing 1.5% of Al, out of the invention, show that it is possible with such steels to obtain not too bad yield and tensile strengths, but the elongations are low due to too high annealing temperatures. The austenite grain size before quenching is too big. The examples 14 to 19, according to the invention which are related to steels containing either more manganese or more carbon than the steel of examples 1 to 9 show that, with such steels it is possible to obtain high yield strength and high tensile strength with a heat treatment comprising an annealing higher than Ac_3, a quenching down to a temperature lower than Ms and an overaging around 400°C. But with these steels, the uniform elongation or the total elongation remain low.

The examples 20 to 22, out of the invention, which correspond to a steel containing no silicon, show that even if the tensile strength is not so bad, the yield stress and the elongation remains low.

CLAIMS

1. A method for manufacturing a high-strength steel sheet having a tensile strength of more than 1100 MPa and a yield strength of more than 700 MPa, made of a steel containing in percent by weight:

$0.1\% \leq C \leq 0.35\%$

$4.5\% \leq Mn \leq 10\%$

$1\% \leq Si \leq 3\%$

$0.03 \leq Al \leq 2.5\%$

the remainder being Fe and impurities resulting from the smelting,
the method comprising the steps of:

- annealing a rolled sheet made of said steel by soaking it at an annealing temperature TA higher than the Ac_1 transformation point of the steel but less than 1000°C,
- cooling the annealed sheet to a quenching temperature QT less than 450°C,
- maintaining the steel sheet at an overaging temperature PT between 350°C and 500°C for an overaging time Pt of more than 5 s and,
- cooling the sheet down to the ambient temperature.

2. The method according to claim 1, characterized in that the quenching temperature QT is less than the Ms transformation point of the steel and in that the cooling is made at a cooling speed sufficient to obtain a structure containing martensite.

3. The method according to claim 2, characterized in that the annealing temperature TA is higher than the Ac_3 transformation point of the steel, and in that the quenching temperature QT is such that the structure of the steel contains at least 20% of retained austenite and at least 65% of martensite, the sum of the ferrite and bainite contents being less than 10%.

4. The method according to claim 3, characterized in that the chemical composition of the steel is such that:

$0.15\% \leq C \leq 0.25\%$

$4.5\% \leq Mn \leq 5.5\%$

$1.4\% \leq Si \leq 1.8\%$

$0.03 \leq Al \leq 2.5\%$,

in that the annealing temperature AT is higher than 760°C, in that the quenching temperature QT is less than 170°C and in that the structure of the steel contains between 20% and 30% of retained austenite.

5. The method according to claim 4, characterized in that the quenching temperature QT is less than 150°C.

6. The method according to claim 4 or 5, characterized in that the overaging temperature PT is between 380°C and 470°C and in that the sheet is maintained at the overaging temperature for a time Pt between 90 s and 600 s.

7. The method according to claim 3, characterized in that the chemical composition of the steel is such that:

$$0.15\% \leq C \leq 0.25\%$$
$$6.5\% \leq Mn \leq 7.5\%$$
$$1.4\% \leq Si \leq 1.8\%$$
$$0.03 \leq Al \leq 2.5\%$$

and in that the annealing temperature AT is higher than 710°C, the quenching temperature QT is between 120°C and 180°C, the overaging temperature PT is between 350°C and 470°C and the overaging time Pt is between 5 s and 600 s.

8. The method according to claim 3, characterized in that the chemical composition is such that:

$$0.25\% \leq C \leq 0.35\%$$
$$4.5\% \leq Mn \leq 5.5\%$$
$$1.4\% \leq Si \leq 1.8\%$$
$$0.03 \leq Al \leq 2.5\%$$

and in that the annealing temperature is higher than 750°C, the quenching temperature QT is between 100°C and 160°C, the overaging temperature PT is between 350°C and 470°C and the overaging time Pt is between 5 s and 600 s.

9. The method according to claim 2, characterized in that the chemical composition of the steel is such that:

$$0.15\% \leq C \leq 0.25\%$$
$$4.5\% \leq Mn \leq 5.5\%$$
$$1.4\% \leq Si \leq 1.8\%$$

$0.03 \leq Al \leq 2.5\%$

and in that the annealing temperature AT is less than the Ac_3 transformation point of the steel, the quenching temperature QT is between 110°C and 170°C, the overaging temperature AT is between 350°C and 500°C, the overaging time Pt is between 5 s and 600 s, the structure of the steel containing at least 15% of ferrite, at least 50% of martensite and at least 15% of retained austenite.

10. The method according to any one of claims 4 to 9, characterized in that the overaging temperature PT is between 440°C and 470°C and the sheet is maintained at the overaging temperature for a time Pt between 5 s and 60 s.

11. The method according to claim 10, characterized in that at least a part of the holding at the overaging temperature is made by passing the sheet in a hot dip coating bath.

12. The method according to claim 11, characterized in that, after passing in a hot dip coating bath and before cooling down to the ambient temperature, the sheet is further maintained at a temperature between 480°C and 570°C.

13. The method according to any one of claims 1 to 12, characterized in that the annealing, the quenching and the overaging are made on a continuous heat treatment line such as a continuous annealing line.

14. The method according to any one of claims 1 to 11, characterized in that the rolled sheet is prepared by rolling and in that preparation of the sheet by rolling comprises hot rolling and optionally cold rolling.

15. A high-strength steel sheet having a tensile strength of more than 1100 MPa and a yield strength of more than 700 MPa characterized in that the chemical composition of the steel contains, in weight percent:

$0.1\% \leq C \leq 0.35\%$

$4.5\% \leq Mn \leq 10\%$

$1 \leq Si \leq 3\%$

$0.03 \leq Al \leq 2.5\%$

the remainder being Fe and impurities resulting from the smelting.

16. The high-strength steel sheet according to claim 15, characterized in that the structure of the steel contains at least 20% of retained austenite and at least 65% of martensite, the sum of the ferrite and bainite contents being less than 10%.

17. The high-strength steel sheet according to claim 16, characterized in that the chemical composition of the steel is such that:

$0.15\% \leq C \leq 0.25\%$

$4.5\% \leq Mn \leq 5.5\%$

$1.4\% \leq Si \leq 1.8\%$

$0.03 \leq Al \leq 2.5\%$

18. The high-strength steel sheet according to claim 17, characterized in that the yield strength YS is higher than 1100 MPa, the tensile strength TS is higher than 1350 MPa, the uniform elongation UE is of more than 10% and the total elongation TE is of more than 12%.

19. The high-strength steel sheet according to claim 18, characterized in that the chemical composition of the steel is such that:

$0.15\% \leq C \leq 0.25\%$

$6.5\% \leq Mn \leq 7.5\%$

$1.4\% \leq Si \leq 1.8\%$

$0.03 \leq Al \leq 2.5\%$

and in that the yield strength YS is higher than 1000 MPa and the tensile strength TS is higher than 1100 MPa.

20. The high-strength steel sheet according to claim 16, characterized in that the chemical composition of the steel is such that:

$0.25\% \leq C \leq 0.35\%$

$4.5\% \leq Mn \leq 5.5\%$

$1.4\% \leq Si \leq 1.8\%$

$0.03 \leq Al \leq 2.5\%$

and in that the yield strength YS is higher than 900 MPa and the tensile strength TS is higher than 1200 MPa.

21. The high-strength steel sheet according to claim 17, characterized in that the chemical composition of the steel is such that:

$0.15\% \leq C \leq 0.25\%$

$4.5\% \leq Mn \leq 5.5\%$

$1.4\% \leq Si \leq 1.8\%$

$0.03 \leq Al \leq 2.5\%$

and in that the structure of the steel comprises at least 15% of ferrite, at least 50% of martensite and at least 15% of retained austenite.

22. The high-strength steel sheet according to any one of claims 15 to 21, characterized in that at least one of its faces comprises a metallic coating.

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2014/002285

A. CLASSIFICATION OF SUBJECT MATTER
INV. C21D6/00 C21D8/02 C21D9/46 C22C38/02 C22C38/04 C22C38/06
ADD.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C21D 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, WPI Data, CHEM ABS Data, COMPENDEX, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EMMANUEL DE MOOR ET AL: "Effect of Carbon and Manganese on the Quenching and Partitioning Response of CMnSi Steels", ISIJ INTERNATIONAL, vol. 51, no. 1, 1 January 2011 (2011-01-01), pages 137-144, XP055172758, ISSN: 0915-1559, DOI: 10.2355/isijinternational.51.137	1-3,8, 10-15, 20,22
A	sections "Introduction", "Experimental procedure"; second and third paragraphs of the right column on page 140; figures 1, 2, 4, 10, 12; tables 1, 6, 9	4-7,9, 16-19,21

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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 :

"A" document defining the general state of the art which is not considered to be of particular relevance

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 March 2015	16/03/2015

Name and mailing address of the ISA/	Authorized officer
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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	paragraphs [0001], [0010], [0011], [0013]-[0021]; claim 1; figures 2, 3	8,20
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A	abstract; claims 1-3; tables 1, 4	8,20
A	ZHAO H; SHI J; LI N; WANG C; HU J; HUI W; CAO W: "Effects of Si on the microstructure and mechanical property of medium Mn steel treated by quenching and partitioning process", CHINESE JOURNAL OF MATERIALS RESEARCH, vol. 25, no. 1, 1 February 2011 (2011-02-01), pages 45-50, XP009182871, the whole document	1-22
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A	HUSEYIN AYDIN ET AL: "Effect of Intercritical Heat Treatment on the Microstructure and Mechanical Properties of Medium Mn Steels", ISIJ INTERNATIONAL, vol. 53, no. 10, 1 January 2013 (2013-01-01), pages 1871-1880, XP055172683, ISSN: 0915-1559, DOI: 10.2355/isijinternational.53.1871 the whole document	1-22

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	SEAWOONG LEE ET AL: "On the Selection of the Optimal Intercritical Annealing Temperature for Medium Mn TRIP Steel", METALLURGICAL AND MATERIALS TRANSACTIONS A, vol. 44, no. 11, 17 July 2013 (2013-07-17) , pages 5018-5024, XP055172687, ISSN: 1073-5623, DOI: 10.1007/s11661-013-1860-2 the whole document -----	1-22

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2014/002285

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