

(12) STANDARD PATENT
(19) AUSTRALIAN PATENT OFFICE

(11) Application No. **AU 2017381869 B2**

(54) Title
A method of dynamical adjustment for manufacturing a thermally treated steel sheet

(51) International Patent Classification(s)
C21D 9/573 (2006.01) **C21D 11/00** (2006.01)
B21B 37/00 (2006.01)

(21) Application No: **2017381869** (22) Date of Filing: **2017.12.20**

(87) WIPO No: **WO18/116192**

(30) Priority Data

(31)	Number	(32)	Date	(33)	Country
	PCT/IB2016/001788		2016.12.20		IB

(43) Publication Date: **2018.06.28**

(44) Accepted Journal Date: **2020.10.08**

(71) Applicant(s)
ArcelorMittal

(72) Inventor(s)
Bonnet, Frédéric;Pham, Van Thang

(74) Agent / Attorney
Phillips Ormonde Fitzpatrick, PO Box 323, Collins Street West, VIC, 8007, AU

(56) Related Art
US 4440583 A



(51) International Patent Classification:

C21D 9/573 (2006.01) *B21B* 37/00 (2006.01)
C21D 11/00 (2006.01)

(21) International Application Number:

PCT/IB2017/058187

(22) International Filing Date:

20 December 2017 (20.12.2017)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

PCT/IB2016/001788

20 December 2016 (20.12.2016) IB

(71) Applicant: **ARCELORMITTAL** [LU/LU]; 24-26, Boulevard d'Avranches, L-1160 Luxembourg (LU).

(72) Inventors: **BONNET, Frédéric**; 5 rue de la Libération, 54150 Avril (FR). **PHAM, Van Thang**; 105 Rue Joseph Henot, 57070 Metz (FR).

(74) Agent: **PLAISANT, Sophie**; ArcelorMittal France, Research & Development, Intellectual Property, 6 rue André Campra, 93200 Saint-Denis (FR).

(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, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, 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, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

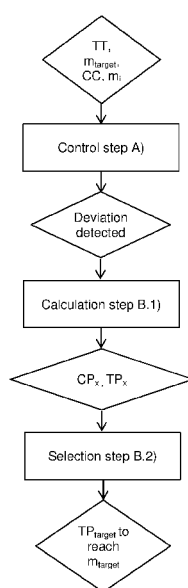
Published:

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

(54) Title: A METHOD OF DYNAMICAL ADJUSTMENT FOR MANUFACTURING A THERMALLY TREATED STEEL SHEET

(57) Abstract: The present invention relates to a method of dynamical adjustment for manufacturing a thermally treated steel sheet.

Figure 1



A method of dynamical adjustment for manufacturing a thermally treated steel sheet

TECHNICAL FIELD

The present invention relates to a method of dynamical adjustment for manufacturing a thermally treated steel sheet having a chemical steel composition and a microstructure m_{target} comprising from 0 to 100% of at least one phase chosen among: ferrite, martensite, bainite, pearlite, cementite and austenite, in a heat treatment line.

BACKGROUND OF THE INVENTION

The following discussion of the background to the invention is intended to facilitate an understanding of the invention. However, it should be appreciated that the discussion is not an acknowledgement or admission that any aspect of the discussion was part of the common general knowledge as at the priority date of the application.

Coated or bare steel sheets are used for the manufacture of automotive vehicles. A multitude of steel grades are used to manufacture a vehicle. The choice of steel grade depends on the final application of the steel part. For example, IF (Interstitial-Free) steels can be produced for an exposed part, TRIP (Transformation-Induced Plasticity) steels can be produced for seat and floor cross members or A-pillars and DP (Dual Phase) steels can be produced for rear rails or roof cross member.

During the production of these steels, crucial treatments are performed on the steel in order to obtain the desired part having expected mechanical properties for one specific application. Such treatments can be, for example, a continuous annealing before deposition of a metallic coating or a quenching and partitioning treatment. In these treatments, the cooling step is important because the microstructure and the mechanical properties of steels mostly depend on the performed cooling treatment. Usually, the treatment including the cooling step to perform is selected in a list of known treatments, this treatment being chosen depending on the steel grade.

However, during these treatments, some unplanned deviations can appear online. For example, a temperature in the furnace, the thickness of the steel sheet, the line speed can vary.

The patent application US4440583 relates to a method of controlled cooling for steel strip implemented by use of a cooling apparatus comprising a plurality of nozzles disposed in the direction in which strip travels, the nozzles spraying coolant against the hot running strip, and a flow-rate control valve attached to the pipe that supplies the coolant to the nozzles. By using an equation containing the thickness of strip, the cooling starting and finishing temperatures, and the desired cooling rate, the heat transfer rate needed to obtain the desired cooling rate is calculated, and the obtained heat transfer rate is corrected according to the effect of natural cooling in idle-pass zones preceding and following the coolant spray zone. Then the flow rate of the coolant is derived, and set, from its pre-established relationship with the heat transfer rate. The length of the coolant spraying zone along the strip travel path is calculated using the running speed of the strip, the cooling starting and finishing temperatures, and the desired cooling rate. The nozzles are set to turn on and off so that coolant is sprayed from only such a number of nozzles as correspond to the calculated value. When strip thickness varies while controlled cooling is being effected, the heat transfer rate is re-calculated, on the basis of the above settings, to correct the coolant flow rate accordingly. When strip speed varies, the length of the coolant spraying region is re-calculated to correct the on-off pattern of the nozzles.

In this method, when a deviation appears, the heat transfer rate or the length of the coolant spraying region is re-calculated to correct the deviation. This method does not take into account the steel sheet characteristics comprising chemical composition, microstructure, properties, surface texture, etc. Thus, there is a risk that the same correction is applied to any kind of steel sheet even if each steel sheet has its own characteristics. The method allows for a non-personalized cooling treatment of a multitude of steel grades.

Consequently, the correction is not adapted to one specific steel and therefore at the end of the treatment, the desired properties are not obtained. Moreover, after the treatment, the steel can have a big dispersion of the

mechanical properties. Finally, even if a wide range of steel grades can be manufactured, the quality of the treated steel is poor.

Thus, it is desirable to address the above drawbacks by providing a method of dynamical adjustment for manufacturing a thermally treated steel sheet having a specific chemical steel composition and a specific microstructure m_{target} to reach in a heat treatment line. In particular, it is desirable to adjust a cooling treatment online by providing a treatment adapted to each steel sheet, such treatment being calculated very precisely in the lowest calculation time possible in order to provide a steel sheet having the expected properties, such properties having the minimum of properties dispersion possible.

SUMMARY OF THE INVENTION

According to one form of the invention, there is provided a method of dynamical adjustment for manufacturing a thermally treated steel sheet having a chemical steel composition and a microstructure m_{target} comprising from 0 to 100% of at least one phase chosen among: ferrite, martensite, bainite, pearlite, cementite and austenite, in a heat treatment line comprising a heating section, a soaking section and a cooling section including a cooling system, wherein a predefined thermal treatment TT, comprising at least a heating, a soaking and a cooling steps, is performed, such method comprising:

A. a control step wherein at least one detector detects any deviation happening during TT,

B. a calculation step performed when a deviation is detected during TT such that a new thermal path TP_{target} is determined to reach m_{target} taking the deviation into account, such calculation step comprising:

1) a calculation sub step wherein through variation of the cooling power, new cooling paths CP_x are calculated based on TT, the initial microstructure m_i of the steel sheet to reach m_{target} , the heating path, the soaking path comprising T_{soaking} and T_{cooling} , the cooling step of TT being recalculated using said CP_x in order to obtain new thermal paths TP_x , having the cooling step replaced by one CP_x in order to obtain a thermal path TP_x , each TP_x corresponding to a microstructure m_x ,

3a

- 2) a selection step wherein one TP_{target} to reach m_{target} is selected, TP_{target} being chosen among the calculated thermal paths TP_x and being selected such that m_x is the closest to m_{target} and

5 C. a new thermal treatment step wherein TP_{target} is performed online on the steel sheet.

According to the invention there is also provided a coil, a thermally treatment line and a computer program, all of which will be described in further detail in the detailed description.

Other characteristics and advantages of the invention will become apparent from the following detailed description of the invention.

Where any or all of the terms "comprise", "comprises", "comprised" or "comprising" are used in this specification (including the claims) they are to be interpreted as specifying the presence of the stated features, integers, steps or components, but not precluding the presence of one or more other features, integers, steps or components.

BRIEF DESCRIPTION OF THE DRAWINGS

10 To illustrate the invention, various embodiments and trials of non-limiting examples will be described, particularly with reference to the following Figures:

Figure 1 illustrates an example according to the present invention.

Figure 2 illustrates a continuous annealing of a steel sheet comprising a heating step, a soaking step, a cooling step and an overaging step.

15 Figure 3 illustrates a preferred embodiment according to the present invention.

Figure 4 illustrates one example according to the invention wherein a continuous annealing is performed on a steel sheet before the deposition of a coating by hot-dip.

20 DETAILED DESCRIPTION

The following terms will be defined:

- CC: chemical composition in percentage in weight percent,
- m_{target} : targeted value of the microstructure,
- m_{standard} : the microstructure of the selected product,

3b

- 5
- P_{target} : targeted value of a mechanical property,
 - m_i : initial microstructure of the steel sheet,
 - X : phase fraction in weight percent,
 - T : temperature in degree Celsius ($^{\circ}\text{C}$),
 - t : time (s),
 - s : seconds,
 - UTS: ultimate tensile strength (MPa)
 - YS: yield stress (MPa)

- metallic coating based on zinc means a metallic coating comprising above 50% of zinc,

- metallic coating based on aluminum means a metallic coating comprising above 50% of aluminum and

5 - TT: thermal treatment and

- thermal path, TT, TP_{target} and TP_x comprises a time, a temperature of the thermal treatment and at least one rate chosen from: a cooling, an isotherm or a heating rate,

- a heating path comprises a time, a temperature and a heating rate,

10 - a soaking path comprises a time, a temperature and a soaking rate,

- CP_x and CP_{xint} comprise a time, a temperature and a cooling rate and

- nanofluids: fluid comprising nanoparticles.

The designation "steel" or "steel sheet" means a steel sheet, a coil, a plate having a composition allowing the part to achieve a tensile strength up to 2500
15 MPa and more preferably up to 2000MPa. For example, the tensile strength is above or equal to 500 MPa, preferably above or equal to 1000 MPa, advantageously above or equal to 1500 MPa. A wide range of chemical composition is included since the method according to the invention can be applied to any kind of steel.

20 The invention relates to a method of dynamical adjustment for manufacturing a thermally treated steel sheet having a chemical steel composition and a microstructure m_{target} comprising from 0 to 100% of at least one phase chosen among: ferrite, martensite, bainite, pearlite, cementite and austenite, in a heat treatment line comprising a heating section, a soaking section and a cooling
25 section including a cooling system, wherein a predefined thermal treatment TT, comprising at least a heating, a soaking and a cooling steps, is performed, such method comprising:

A. a control step wherein at least one detector detects any deviation happening during TT,

30 B. a calculation step performed when a deviation is detected during TT such that a new thermal path TP_{target} is determined to reach m_{target} taking the deviation into account, such calculation step comprising:

1) a calculation sub step wherein through variation of the cooling power, new cooling paths CP_x are calculated based on TT, the initial microstructure m_i of the steel sheet to reach m_{target} , the heating path, the soaking path comprising $T_{soaking}$ and $T_{cooling}$, the cooling step of TT being recalculated using said CP_x in order to obtain new thermal paths TP_x , each TP_x corresponding to a microstructure m_x ,

2) a selection step wherein one TP_{target} to reach m_{target} is selected, TP_{target} being chosen among the calculated thermal paths TP_x and being selected such that m_x is the closest to m_{target} and

C. a new thermal treatment step wherein TP_{target} is performed online on the steel sheet.

Without willing to be bound by any theory, it seems that when the method according to the present invention is applied, it is possible to correct any deviation happening during a thermal treatment by providing a personalized heat treatment comprising a personalized cooling path which depends on each steel sheet. Thus, a precise new thermal path TP_{target} is calculated in a short calculation time taking into account m_{target} , in particular the proportion of all the phases during the cooling path, m_i (including the microstructure dispersion along the steel sheet) and the deviation. Indeed, the method according to the present invention takes into account for the calculation the thermodynamically stable phases, i.e. ferrite, austenite, cementite and pearlite, and the thermodynamic metastable phases, i.e. bainite and martensite. Thus, a steel sheet having the expected properties with the minimum of properties dispersion possible is obtained.

Preferably, the microstructures m_x , m_{target} and m_i phases are defined by at least one element chosen from: the size, the shape and the chemical composition.

Preferably, TT further comprises a pre-heating step. More preferably, TT further comprises a hot-dip coating step, an overaging step or a partitioning step.

Preferably, the microstructure m_{target} to reach comprises:

- 100% of austenite,
- from 5 to 95% of martensite, from 4 to 65% of bainite, the balance being ferrite,
- from 8 to 30% of residual austenite, from 0.6 to 1.5% of carbon in solid solution, the balance being ferrite, martensite, bainite, pearlite and/or cementite,

6

- from 1% to 30% of ferrite and from 1% to 30% of bainite, from 5 and 25% of austenite, the balance being martensite ,

- from 5 to 20% of residual austenite, the balance being martensite,

- ferrite and residual austenite,

5 - residual austenite and intermetallic phases,

- from 80 to 100% of martensite and from 0 to 20% of residual austenite

- 100% martensite,

- from 5 to 100% of pearlite and from 0 to 95% of ferrite and

- at least 75% of equiaxed ferrite, from 5 to 20% of martensite and bainite in

10 amount less than or equal to 10%.

Advantageously, the steel sheets can be any kind of steel grade including Dual Phase DP, Transformation Induced Plasticity (TRIP), Quenched & Partitioned steel (Q&P), Twins Induced Plasticity (TWIP), Carbide Free Bainite (CFB), Press Hardening Steel (PHS), TRIPLEX, DUPLEX and Dual Phase High Ductility (DP

15 HD).

The chemical composition depends on each steel sheet. For example, the chemical composition of a DP steel can comprise:

$$0.05 < C < 0.3\%,$$

$$0.5 \leq Mn < 3.0\%,$$

20 $S \leq 0.008\%,$

$$P \leq 0.080\%,$$

$$N \leq 0.1\%,$$

$$Si \leq 1.0\%,$$

the remainder of the composition making up of iron and inevitable impurities

25 resulting from the development.

Figure 1 illustrates an example according to the invention wherein a TT is performed on a steel sheet in a heat treatment line, such steel sheet having a chemical composition CC and m_{target} to reach.

According to the present invention in step A), any deviation happening

30 during the thermal treatment is detected. Preferably, the deviation is due to a variation of a process parameter chosen from among: a furnace temperature, a steel sheet temperature, an amount of gas, a gas composition, a gas temperature,

a line speed, a failure in the heat treatment line, a variation of the hot-dip bath, a steel sheet emissivity and a variation of the steel thickness.

A furnace temperature can be a heating temperature, a soaking temperature, a cooling temperature, an overaging temperature.

5 A steel sheet temperature can be measured at any time of the heat treatment in different positions of the heat treatment line, for example:

- in a heating section preferably being a direct flame furnace (DFF), a radiant tube furnace (RTF), an electrical resistance furnace or an induction furnace,
- in cooling section, in particular, in jets cooling, in a quenching system or in a
- 10 snout and
- in isothermal section preferably being an electrical resistance furnace.

To detect a temperature variation, the detector can be a pyrometer or a scanner.

Usually, heat treatments can be performed in an oxidizing atmosphere, i.e. an atmosphere comprising an oxidizing gas being for example: O_2 , CO_2 or CO . They also can be performed in a neutral atmosphere, i.e. an atmosphere comprising a neutral gas being for example: N_2 , Ar, He or Xe. Finally, they also can be performed in a reducing atmosphere, i.e. an atmosphere comprising a reducing gas being for example: H_2 or HN_x .

20 The variation of gas amount can be detected by barometer.

The line speed can be detected by a laser detector.

For example, a failure in the heat treatment line can be:

- in a direct flame furnace: a burner not working anymore,
- in a radiant tube furnace: a radiant tube not working anymore,
- 25 - in an electrical furnace: a resistance not working anymore or
- in a cooling section: one or several jets cooling not working anymore.

In such cases, detector can be a pyrometer, a barometer, an electrical consumption or a camera.

30 The variation of the steel thickness can be detected by a laser or an ultrasound detector.

When a deviation is detected, through variation of the cooling power, new cooling paths CP_x are calculated based on TT , m_i to reach m_{target} , the heating path, the soaking path comprising $T_{soaking}$ and $T_{cooling}$, the cooling step of TT being

recalculated using said CP_x in order to obtain new thermal paths TP_x , each TP_x corresponding to a microstructure m_x . The calculation of CP_x is based on the thermal behavior and metallurgical behavior of the steel sheet compared to the conventional methods wherein only the thermal behavior is considered.

5 Figure 2 illustrates a continuous annealing of a steel sheet comprising a heating step, a soaking step, a cooling step and an overaging step. A deviation D due to a variation of T_{soaking} is detected. Thus, a multitude of CP_x and therefore TP_x are calculated such that TP_{standard} , being selected among TP_x , reach m_{target} as shown only for the first cooling step in Figure 2. In this example, the calculated
10 CP_x also includes the second cooling step (not shown).

Preferably, in step B.1), the cooling power of the cooling system varies from a minimum to a maximum value or from a maximum to a minimum value. For example, the cooling system comprises at least one jet cooling, at least one cooling spray or at least both. Preferably, the cooling system comprises at least
15 one jet cooling, the jet cooling spraying a fluid being a gas, an aqueous liquid or a mixture thereof. For example, the gas is chosen from air, HN_x , H_2 , N_2 , Ar, He, steam water or a mixture thereof. For example, the aqueous liquid is chosen from: water or nanofluids.

Preferably, jets cooling spray gas with a flow rate between 0 and
20 $350000 \text{ Nm}^3/\text{h}$. The number of jets cooling present in the cooling section depends on the heat treatment line, it can vary from 1 to 25, preferably from 1 to 20, advantageously from 1 to 15 and more preferably between from 1 and 5. The flow rate depends on the number of jets cooling. For example, the flow rate of one jet cooling is between 0 and $50000 \text{ Nm}^3/\text{h}$, preferably between 0 and $40000 \text{ Nm}^3/\text{h}$,
25 more preferably between 0 and $20000 \text{ Nm}^3/\text{h}$.

When the cooling section comprises jets cooling, the variation of cooling power is based on the flow rate. For example, for one jet cooling, $0 \text{ Nm}^3/\text{h}$ corresponds to a cooling power of 0% and $40000 \text{ Nm}^3/\text{h}$ corresponds to a cooling power of 100%.

30 Thus, for example, the cooling power of one jet cooling varies from a 0 Nm^3/h , i.e. 0%, to $40000 \text{ Nm}^3/\text{h}$, i.e. 100%. The minimum and maximum value of the cooling power can be any value chosen in the range of 0 to 100%. For

example, the minimum value is of 0%, 10%, 15% or 25%. For example, the maximum value is of 80%, 85%, 90% or 100%.

When the cooling section comprises at least 2 jets cooling, the cooling power can be the same or different on each jet cooling. It means that each jet cooling can be configured independently of one other. For example, when the cooling section comprising 11 jets cooling, the cooling power of the three first jets cooling can be of 100%, the cooling power of the following four can be of 45% and the cooling power of the last four can be of 0%.

For example, the variation of the cooling power has an increment between 5 to 50%, preferably between 5 to 40%, more preferably between 5 to 30% and advantageously between 5 to 20%. The cooling power increment is, for example, of 10%, 15% or 25%.

When the cooling section comprises at least 2 jets cooling, the cooling power increment can be the same or different on each jet cooling. For example, in step B.1), the cooling power increment can be of 5% on all the jets cooling. In another embodiment, the cooling power increment can be of 5% for the three first jets, 20% for the following four and 15% for the last four. Preferably, the cooling power increment is different for each jet cooling, for example 5% for the first jet, 20% for the second jet, 0% for the third jet, 10% for the fourth jet, 0% for the fifth jet, 35% of the sixth jet, etc.

In a preferred embodiment, the cooling systems are configured depending on the phase transformation independently of one other. For example, when the cooling system comprises 11 jets cooling, the cooling power of the three first jets cooling can be configured for the transformation, the cooling power of the following four can be configured for the transformation of austenite into perlite and the cooling power of the last four can be configured for the transformation of austenite into bainite. In another embodiment, the cooling power increment can be different for each jet cooling.

Preferably, in step B.1), T_{soaking} is a fixed number selected from the range between 600 to 1000°C. For example, T_{soaking} can be of 700°C, 800°C or 900°C depending on the steel sheet.

In another preferred embodiment, T_{soaking} varies from 600 to 1000°C. For example, T_{soaking} can vary from 650 to 750°C or from 800 to 900°C depending on the steel sheet.

Advantageously, when T_{soaking} varies, after step B.1), a further calculation sub step is performed wherein:

- a. T_{soaking} varies from in a predefined range value being between 600 and 1000°C and
- b. For each T_{soaking} variation, new cooling paths CP_x are calculated, based on TT, m_i to reach m_{standard} and T_{cooling} , the cooling step of TT being recalculated using said CP_x in order to obtain new thermal paths TP_x , each TP_x corresponding to a microstructure m_x .

Indeed, with the method according to the present invention, the variation of T_{soaking} is taken into consideration for the calculation of CP_x . Thus, for each temperature of soaking, a multitude of new cooling paths CP_x and therefore new TP_x are calculated.

Preferably, at least 10 CP_x are calculated, more preferably at least 50, advantageously at least 100 and more preferably at least 1000. For example, the number of calculated CP_x is between 2 and 10000, preferably between 100 and 10000, more preferably between 1000 and 10000.

In step B.2), one TP_{target} to reach m_{target} is selected, TP_{target} being chosen from TP_x and being selected such that m_x is the closest to m_{target} . Preferably, the differences between phases proportions present in m_{target} and m_x is $\pm 3\%$.

Preferably, in step B.2), when at least two CP_x have their m_x equal, the selected TP_{target} selected is the one having the minimum cooling power needed.

Advantageously, when T_{soaking} varies, the selected TP_{target} further includes the value of T_{soaking} to reach m_{target} , TP_{target} being chosen from TP_x .

Advantageously, in step B.2), the thermal enthalpy H_{released} between m_i and m_{target} is calculated such that:

$$H_{\text{released}} = (X_{\text{ferrite}} * H_{\text{ferrite}}) + (X_{\text{martensite}} * H_{\text{martensite}}) + (X_{\text{bainite}} * H_{\text{bainite}}) + (X_{\text{pearlite}} * H_{\text{pearlite}}) + (H_{\text{cementite}} + X_{\text{cementite}}) + (H_{\text{austenite}} + X_{\text{austenite}})$$

X being a phase fraction.

Without willing to be bound by any theory, H represents the energy released along the all thermal path when a phase transformation is performed. It is believed that some phase transformations are exothermic and some of them are endothermic. For example, the transformation of ferrite into austenite during a heating path is endothermic whereas the transformation of austenite into pearlite during a cooling path is exothermic.

In a preferred embodiment, in step B.2), the all thermal cycle CP_x is calculated such that:

$$T(t + \Delta t) = T(t) + \frac{(\varphi_{Convection} + \varphi_{radiance})}{\rho \cdot Ep \cdot C_{pe}} \Delta t \pm \frac{H_{released}}{C_{pe}}$$

with C_{pe} : the specific heat of the phase ($J \cdot kg^{-1} \cdot K^{-1}$), ρ : the density of the steel ($g \cdot m^{-3}$), Ep : the thickness of the steel (m), φ : the heat flux (convective and radiative in W), $H_{released}$ ($J \cdot kg^{-1}$), T : temperature ($^{\circ}C$) and t : time (s).

Preferably, in step B.2), at least one intermediate steel microstructure m_{xint} corresponding to an intermediate thermal path CP_{xint} and the thermal enthalpy H_{xint} are calculated. In this case, the calculation of CP_x is obtained by the calculation of a multitude of CP_{xint} . Thus, preferably, CP_x is the sum of all CP_{xint} and $H_{released}$ is the sum of all H_{xint} . In this preferred embodiment, CP_{xint} is calculated periodically. For example, it is calculated every 0.5 seconds, preferably 0.1 seconds or less.

Figure 3 illustrates a preferred embodiment wherein in step B.1), m_{int1} and m_{int2} corresponding respectively to CP_{xint1} and CP_{xint2} as well as H_{xint1} and H_{xint2} are calculated. $H_{released}$ during the all thermal path is determined to calculate CP_x . In this embodiment, a multitude, i.e more than 2, of CP_{xint} , m_{xint} and H_{xint} are calculated to obtain CP_x (not shown).

In a preferred embodiment, before step A.1), at least one targeted mechanical property P_{target} chosen among yield strength YS, Ultimate Tensile Strength UTS, elongation, hole expansion, formability is selected. In this embodiment, preferably, m_{target} is calculated based on P_{target} .

Without willing to be bound by any theory, it is believed that the characteristics of the steel sheet are defined by the process parameters applied during the steel production. Thus, advantageously, in step B.1), the process parameters

undergone by the steel sheet before entering the heat treatment line are taken into account to calculate CP_x . For example, the process parameters comprise at least one element chosen from among: a cold rolling reduction rate, a coiling temperature, a run out table cooling path, a cooling temperature and a coil cooling rate.

In another embodiment, the process parameters of the treatment line that the steel sheet will undergo in the heat treatment line are taken into account to calculate CP_x . For example, the process parameters comprise at least one element chosen from among: the line speed, a specific thermal steel sheet temperature to reach, heating power of the heating sections, a heating temperature and a soaking temperature, cooling power of the cooling sections, a cooling temperature and an overaging temperature.

Preferably, $T_{cooling}$ is the bath temperature when the cooling section is followed by a hot-dip coating section comprising a hot-dip bath. Preferably, the bath is based on aluminum or based on zinc. In a preferred embodiment, the bath based on aluminum comprises less than 15% Si, less than 5.0% Fe, optionally 0.1 to 8.0% Mg and optionally 0.1 to 30.0% Zn, the remainder being Al.

In another preferred embodiment, the zinc-based bath comprises 0.01-8.0% Al, optionally 0.2-8.0% Mg, the remainder being Zn.

The molten bath can also comprise unavoidable impurities and residuals elements from feeding ingots or from the passage of the steel sheet in the molten bath. For example, the optionally impurities are chosen from Sr, Sb, Pb, Ti, Ca, Mn, Sn, La, Ce, Cr, Zr or Bi, the content by weight of each additional element being inferior to 0.3% by weight. The residual elements from feeding ingots or from the passage of the steel sheet in the molten bath can be iron with a content up to 5.0%, preferably 3.0%, by weight.

In another preferred embodiment, $T_{cooling}$ is the quenching temperature T_q . Indeed, for the Q&P steel sheet, an important point of a quenching & partitioning treatment is T_q .

Preferably, $T_{cooling}$ is between 150 and 800°C.

Advantageously, every time a new steel sheet enters into the heat treatment line, a new calculation step B.2) is automatically performed. Indeed, the method according to the present invention adapts the cooling path to each steel

sheet even if the same steel grade enters in the heat treatment line since the real characteristics of each steel often differs. The new steel sheet can be detected and the new characteristics of the steel sheet are measured and are pre-selected beforehand. For example, a detector detects the welding between two coils.

5 Preferably, the adaptation of the thermal path is performed as the steel sheet entries into the heat treatment line on the first meters of the sheet in order to avoid strong process variation.

 Preferably, an automatic calculation is performed during the thermal treatment to check if any deviation had appeared. In this embodiment, periodically,
10 a calculation is realized to verify if a slight deviation had occurred. Indeed, the detection threshold of detector is sometimes too high which means that a slight deviation is not always detected. The automatic calculation, performed for example every few seconds, is not based on a detection threshold. Thus, if the calculation leads to the same thermal treatment, i.e. the thermal treatment
15 performs online, TT will not change. If the calculation leads to a different treatment due to a slight deviation, the treatment will change.

 Figure 4 illustrates one example according to the invention wherein a continuous annealing is performed on a steel sheet before the deposition of a coating by hot-dip. With the method according to the present invention, when a
20 deviation D appears, TP_x is calculated based on m_i , the selected product, TT and m_{target} . In this example, intermediate thermal paths CP_{xint1} to CP_{xint4} , corresponding respectively m_{xint1} to m_{xint4} , and H_{xint1} to H_{xint4} are calculated. $H_{released}$ is determined in order to obtain CP_x and therefore TP_x . In this Figure, TP_{target} is illustrated.

 With the method according to the present invention, when a deviation
25 appears, a new a thermal treatment step TP_{target} is performed on the steel sheet.

 Thus, a coil made of a steel sheet including said predefined product types include DP, TRIP, Q&P, TWIP, CFB, PHS, TRIPLEX, DUPLEX, DP HD is obtained, such coil having a standard variation of mechanical properties below or equal to 25MPa, preferably below or equal to 15MPa, more preferably below or
30 equal to 9 MPa, between any two points along the coil. Indeed, without willing to be bound by any theory, it is believed that the method including the calculation step B.1) takes into account the microstructure dispersion of the steel sheet along

the coil. Thus, TP_{target} applied on the steel sheet allows for a homogenization of the microstructure and also of the mechanical properties.

Preferably, the mechanical properties are chosen from YS, UTS or elongation. The low value of standard variation is due to the precision of TP_{target} .

5 Preferably, the coil is covered by a metallic coating based on zinc or based on aluminum.

Preferably, in an industrial production, between two coils made of a steel sheet including said predefined product types include DP, TRIP, Q&P, TWIP, CFB, PHS, TRIPLEX, DUPLEX, DP HD, the standard variation of mechanical properties
10 below or equal to 25MPa, preferably below or equal to 15MPa, more preferably below or equal to 9 MPa.

Preferably, in an industrial production, the standard variation of mechanical properties between 2 coils made of a steel sheet including said predefined product types include DP, TRIP, Q&P, TWIP, CFB, PHS, TRIPLEX, DUPLEX, DP HD
15 measured successively produced on the same line is below or equal to 25MPa, preferably below or equal to 15MPa, more preferably below or equal to 9 MPa.

A thermally treatment line for the implementation of a method according to the present invention is used to perform TP_{target} . For example, the thermally treatment line is a continuous annealing furnace, a press hardening furnace, a
20 batch annealing or a quenching line.

Finally, the present invention relates to a Computer program product comprising at least a metallurgical module, an optimization module and a thermal module that cooperate together to determine TP_{target} such modules comprising software instructions that when implemented by a computer implement the method
25 according to the present invention.

The metallurgical module predicts the microstructure (m_x , m_{target} including metastable phases: bainite and martensite and stables phases: ferrite, austenite, cementite and pearlite) and more precisely the proportion of phases all along the treatment and predicts the kinetic of phases transformation.

30 The thermal module predicts the steel sheet temperature depending on the installation used for the thermal treatment, the installation being for example a continuous annealing furnace, the geometric characteristics of the band, the process parameters including the power of cooling, heating or isotherm power, the

thermal enthalpy H released or consumed along the all thermal path when a phase transformation is performed.

The optimization module determines the best thermal path to reach m_{target} , i.e. TP_{target} following the method according to the present invention using the metallurgical and thermal modules. The invention will now be explained in trials carried out for information only. They are not limiting.

Examples

In the following examples, DP780GI having the following chemical composition was chosen :

C (%)	Mn (%)	Si (%)	Cr (%)	Mo (%)	P (%)	Cu (%)	Ti (%)	N (%)
0.145	1.8	0.2	0.2	0.0025	0.015	0.02	0.025	0.06

The cold-rolling had a reduction rate of 55% to obtain a thickness of 1.2mm. m_{target} to reach comprises 12% of martensite, 58% of ferrite and 30% of bainite, corresponding to the following P_{target} : YS of 460MPa and UTS of 790MPa. A cooling temperature T_{cooling} of 460°C has also to be reached in order to perform a hot-dip coating with a zinc bath. This temperature must be reached with an accuracy of +/- 2°C to guarantee good coatability in the Zn bath.

The thermal treatment TT to perform on the steel sheet, is as follows:

- a pre-heating step wherein the steel sheet is heated from ambient temperature to 680°C during 37.5 seconds,
- a heating step wherein the steel sheet is heated from 680°C to 780°C during 40 seconds,
- soaking step wherein the steel sheet is heated at a soaking temperature T_{soaking} of 780°C during 24.4 seconds,
- a cooling step wherein the steel sheet is cooled with 11 jets cooling spraying HN_x as follows:

Jets	Jet 1	Jet 2	Jet 3	Jet 4	Jet 5	Jet 6	Jet 7	Jet 8	Jet 9	Jet 10	Jet 11
Cooling rate (°C/s)	10	10	9	5	9	22	50	18	18	21	11
Time (s)	1.89	1.89	1.89	1.89	1.68	1.8	1.8	1.63	1.63	1.63	1.63

16

T(°C)	754	734	718	708	693	653	563	533	504	481	463
Cooling power(%)	0	0	0	0	0	0	28	100	100	100	100

- a hot-dip coating in a zinc bath à 460°C,
- the cooling of the steel sheet until the top roll during 27.8s at 300°C and
- the cooling of the steel sheet at ambient temperature.

5 Example 1: deviation of T_{soaking}

When the soaking temperature T_{soaking} decreased from 780°C to 765°C, a new thermal path TP_{target1} is determined to reach m_{target} taking the deviation into account. To this end, a multitude of thermal path CP_x is calculated based on TT, m_i of DP780GI to reach m_{target} , the heating path, the soaking path comprising T_{soaking} and T_{cooling} .

The cooling step of TT was recalculated using said CP_x in order to obtain new thermal paths TP_x . After the calculation of TP_x , one TP_{target} to reach m_{target} was selected, TP_{target} being chosen from the recalculated TP_x and being selected such that m_x is the closest to m_{target} . TP_{target1} is as follows:

- a soaking step wherein the steel sheet is heated at a soaking temperature T_{soaking} of 765°C during 24.4seconds due to a deviation in the soaking section of the heat treatment line,
 - a cooling step CP_1 including:
 - a cooling step wherein the steel sheet is cooled with 11 jets cooling spraying HN_x
- as follows:

Jets	Jet 1	Jet 2	Jet 3	Jet 4	Jet 5	Jet 6	Jet 7	Jet 8	Jet 9	Jet 10	Jet 11
Cooling rate (°C/s)	9	9	10	15	32	28	31	11	10	7	8
Time (s)	1.89	1.89	1.89	1.89	1.68	1.8	1.8	1.63	1.63	1.63	1.63
T(°C)	742	725	706	679	625	574	518	500	483	472	459
Cooling power(%)	0	0	0	25	50	50	45	45	45	45	45

- a hot-dip coating in a zinc bath à 460°C,
- the cooling of the steel sheet until the top roll during 27.8s at 300°C and
- the cooling of the steel sheet at ambient temperature.

Example 2: steel sheet having a different composition

A new steel sheet DP780 entered into the heat treatment line so a calculation step was automatically performed based on the following new CC:

C(%)	Mn(%)	Si(%)	Cr(%)	Mo(%)	P(%)	Cu(%)	Ti(%)	N(%)
0.153	1.830	0.225	0.190	0.0025	0.015	0.020	0.025	0.006

5

The new thermal path TP_{target2} was determined to reach m_{target} taking the new CC into account. TP_{target2} is as follows:

- a pre-heating step wherein the steel sheet is heated from ambient temperature to 680°C during 37.5 seconds,
- a heating step wherein the steel sheet is heated from 680°C to 780°C during 40 seconds,
- a soaking step wherein the steel sheet is heated at a soaking temperature T_{soaking} of 780°C during 24.4 seconds,
- a cooling step CP_3 including:

15

Jets	Jet 1	Jet 2	Jet 3	Jet 4	Jet 5	Jet 6	Jet 7	Jet 8	Jet 9	Jet 10	Jet 11
Cooling rate (°C/s)	17	17	9	6	6	6	38	30	18	17	10
Time (s)	2.2	2.2	2.2	2.2	1.96	2.1	2.1	1.9	1.9	1.9	1.9
T(°C)	737	705	688	677	667	655	586	537	508	481	464
Cooling power(%)	100	100	30	0	0	0	100	100	100	100	100

- a hot-dip coating in a zinc bath à 460°C,
- the cooling of the steel sheet until the top roll during 26.8s at 300°C and
- the cooling of the steel sheet at ambient temperature.

20

Table 1 shows the steel properties obtained with TT, TP_{target1} and TP_{target2} .

	TT	TP_{target1}	TP_{target2}	Expected properties
T_{cooling} obtained (°C)	461	458	462	460

Microstructure obtained at the end of the thermal path	$X_{\text{martensite}}$: 12% X_{ferrite} : 55% X_{bainite} : 33%	$X_{\text{martensite}}$: 12% X_{ferrite} : 61% X_{bainite} : 27%	$X_{\text{martensite}}$: 14% X_{ferrite} : 55% X_{bainite} : 32%	$X_{\text{martensite}}$: 12% X_{ferrite} : 58% X_{bainite} : 30%
Deviation (écart) with respect to m_{target}	$X_{\text{martensite}}$: 0% X_{ferrite} : 3% X_{bainite} : 3%	$X_{\text{martensite}}$: 0% X_{ferrite} : 3% X_{bainite} : 3%	$X_{\text{martensite}}$: 2% X_{ferrite} : 3% X_{bainite} : 2%	-
YS (MPa)	453.5	465	462	460
YS deviation with respect to P_{target} (MPa)	6.5	5	2	-
UTS (MPa)	786.8	790	804	790
UTS deviation with respect to P_{target} (MPa)	3.2	0	14	-

With the method according to the present invention, it is possible to adjust a thermal TT when a deviation appears or when a new steel sheet having a different CC enters into the heat treatment line. By applying the new thermal paths TP_{target1} and TP_{target2} , it is possible to obtain a steel sheet having the desired expected properties, each TP_{target} being precisely adapted depending on each deviation.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS :

1. A method of dynamical adjustment for manufacturing a thermally treated steel sheet having a chemical steel composition and a microstructure m_{target} comprising from 0 to 100% of at least one phase chosen among: ferrite, martensite, bainite, pearlite, cementite and austenite, in a heat treatment line comprising a heating section, a soaking section and a cooling section including a cooling system, wherein a predefined thermal treatment TT, comprising at least a heating, a soaking and a cooling steps, is performed, such method comprising:
- A. a control step wherein at least one detector detects any deviation happening during TT,
 - B. a calculation step performed when a deviation is detected during TT such that a new thermal path TP_{target} is determined to reach m_{target} taking the deviation into account, such calculation step comprising:
 - 1) a calculation sub step wherein through variation of the cooling power, new cooling paths CP_x are calculated based on TT, the initial microstructure m_i of the steel sheet to reach m_{target} , the heating path, the soaking path comprising T_{soaking} and T_{cooling} , the cooling step of TT being recalculated using said CP_x in order to obtain new thermal paths TP_x , having the cooling step replaced by one CP_x in order to obtain a thermal path TP_x , each TP_x corresponding to a microstructure m_x ,
 - 2) a selection step wherein one TP_{target} to reach m_{target} is selected, TP_{target} being chosen among the calculated thermal paths TP_x and being selected such that m_x is the closest to m_{target} and
 - C. a new thermal treatment step wherein TP_{target} is performed online on the steel sheet.
2. Method according to claim 1, wherein in step A), the deviation is due to a variation of one process parameter chosen from among: a furnace

temperature, a steel sheet temperature, an amount of gas, a gas composition, a gas temperature, a line speed, a failure in the heat treatment line, a variation of the hot-dip bath, a steel sheet emissivity and a variation of the steel thickness.

5

3. Method according to claims 1 or 2, wherein the phases are defined by at least one element chosen from: the size, the shape and the chemical composition.

10

4. Method according to any one of claims 1 to 3, wherein the microstructure m_{target} comprises:

15

- 100% of austenite,

- from 5 to 95% of martensite, from 4 to 65% of bainite, the balance being ferrite,

- from 8 to 30% of residual austenite, from 0.6 to 1.5% of carbon in solid solution, the balance being ferrite, martensite, bainite, pearlite and/or cementite,

20

- from 1% to 30% of ferrite and from 1% to 30% of bainite, from 5 and 25% of austenite, the balance being martensite,

- from 5 to 20% of residual austenite, the balance being martensite,

- ferrite and residual austenite,

- residual austenite and intermetallic phases,

- from 80 to 100% of martensite and from 0 to 20% of residual austenite

- 100% martensite,

- from 5 to 100% of pearlite and from 0 to 95% of ferrite and

25

- at least 75% of equiaxed ferrite, from 5 to 20% of martensite and bainite in amount less than or equal to 10%.

30

5. Method according to any one of claims 1 to 4, wherein the steel sheet can be Dual Phase, Transformation Induced Plasticity, Quenched & Partitioned steel, Twins Induced Plasticity, Carbide Free Bainite, Press Hardening Steel, TRIPLEX, DUPLEX and Dual Phase High Ductility.

6. Method according to any one of claims 1 to 5, wherein TT further comprises a hot-dip coating step, an overaging step or a partitioning step.
7. Method according to any one of claims 1 to 6, wherein in step B.1), T_{soaking} is a fixed number selected from the range between 600 to 1000°C.
8. Method according to any one of claims 1 to 7, wherein after step B.1), a further calculation sub step is performed wherein:
 - a. T_{soaking} varies from in a predefined range value being between 600 and 1000°C and
 - b. For each T_{soaking} variation, new cooling paths CP_x are calculated, based on TT, m_i to reach m_{standard} and T_{cooling} , the cooling step of TT being recalculated using said CP_x in order to obtain new thermal paths TP_x , each TP_x corresponding to a microstructure m_x .
9. Method according to claim 8, wherein in the selection step B.2), the selected TP_{target} further includes the value of T_{soaking} .
10. Method according to any one of claims 1 to 9, wherein in step B.2), when at least two CP_x have their m_x equal, the selected TP_{target} selected is the one having the minimum cooling power needed.
11. Method according to any one of claims 1 to 10, when in step B.1), the differences between phases proportions present in m_{target} and m_x is $\pm 3\%$.
12. Method according to any one of claims 1 to 11, wherein in step B.1), the thermal enthalpy H released between m_i and m_{target} is calculated such that:

$$H_{\text{released}} = (X_{\text{ferrite}} * H_{\text{ferrite}}) + (X_{\text{martensite}} * H_{\text{martensite}}) + (X_{\text{bainite}} * H_{\text{bainite}}) + (X_{\text{pearlite}} * H_{\text{pearlite}}) + (H_{\text{cementite}} + X_{\text{cementite}}) + (H_{\text{austenite}} + X_{\text{austenite}})$$
 X being a phase fraction.
13. Method according to claim 12, wherein in step B.1), the all cooling path CP_x is calculated such that:

$$T(t + \Delta t) = T(t) + \frac{(\varphi_{Convection} + \varphi_{radiance})}{\rho \cdot Ep \cdot C_{pe}} \Delta t \pm \frac{H_{released}}{C_{pe}}$$

with Cpe: the specific heat of the phase (J.kg⁻¹.K⁻¹), ρ: the density of the steel (g.m⁻³), Ep: thickness of the steel (m), φ: the heat flux (convective and radiative in W), H_{released} (J.kg⁻¹), T: temperature (°C) and t: time (s).

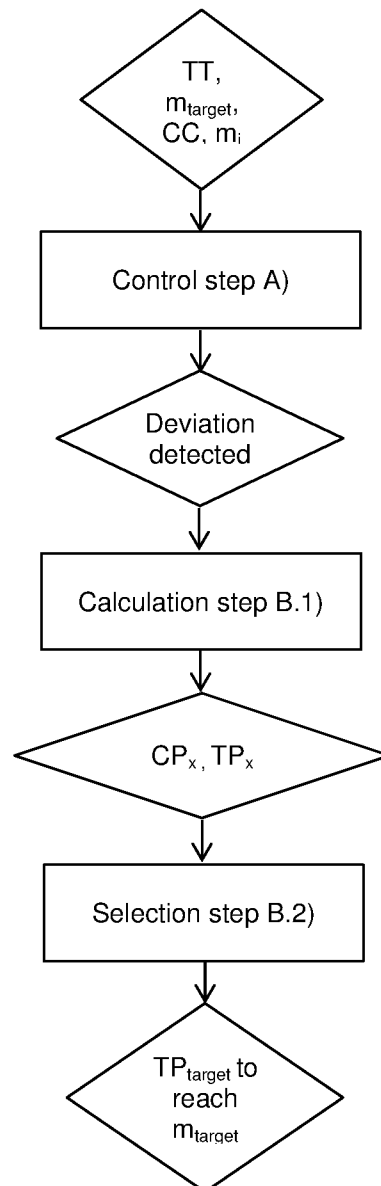
14. Method according to any one of claims 12 or 13, wherein in step B.1), at least one intermediate steel microstructure m_{xint} corresponding to an intermediate cooling path CP_{xint} and the thermal enthalpy H_{xint} are calculated.
15. Method according to claim 14, wherein in step B.1), CP_x is the sum of all CP_{xint} and H_{released} is the sum of all H_{xint}.
16. Method according to any one of claims 1 to 15, wherein before step A.1.a), at least one targeted mechanical property P_{target} chosen among yield strength YS, Ultimate Tensile Strength UTS, elongation hole expansion, formability is selected.
17. Method according to any one of claims 1 to 16, wherein in step B.1), the process parameters undergone by the steel sheet before entering the heat treatment line are taken into account to calculate CP_x.
18. Method according to claim 17, wherein the process parameters comprise at least one element chosen from among: a cold rolling reduction rate, a coiling temperature, a run out table cooling path, a cooling temperature and a coil cooling rate.
19. Method according to any one of claims 1 to 18, wherein in step B.1) the process parameters of the treatment line that the steel sheet will undergo in the heat treatment line are taken into account to calculate CP_x.
20. Method according to claim 19, wherein the process parameters comprise at least one element chosen from among: a specific thermal steel sheet temperature to reach, the line speed, cooling power of the cooling sections,

heating power of the heating sections, an overaging temperature, a cooling temperature, a heating temperature and a soaking temperature.

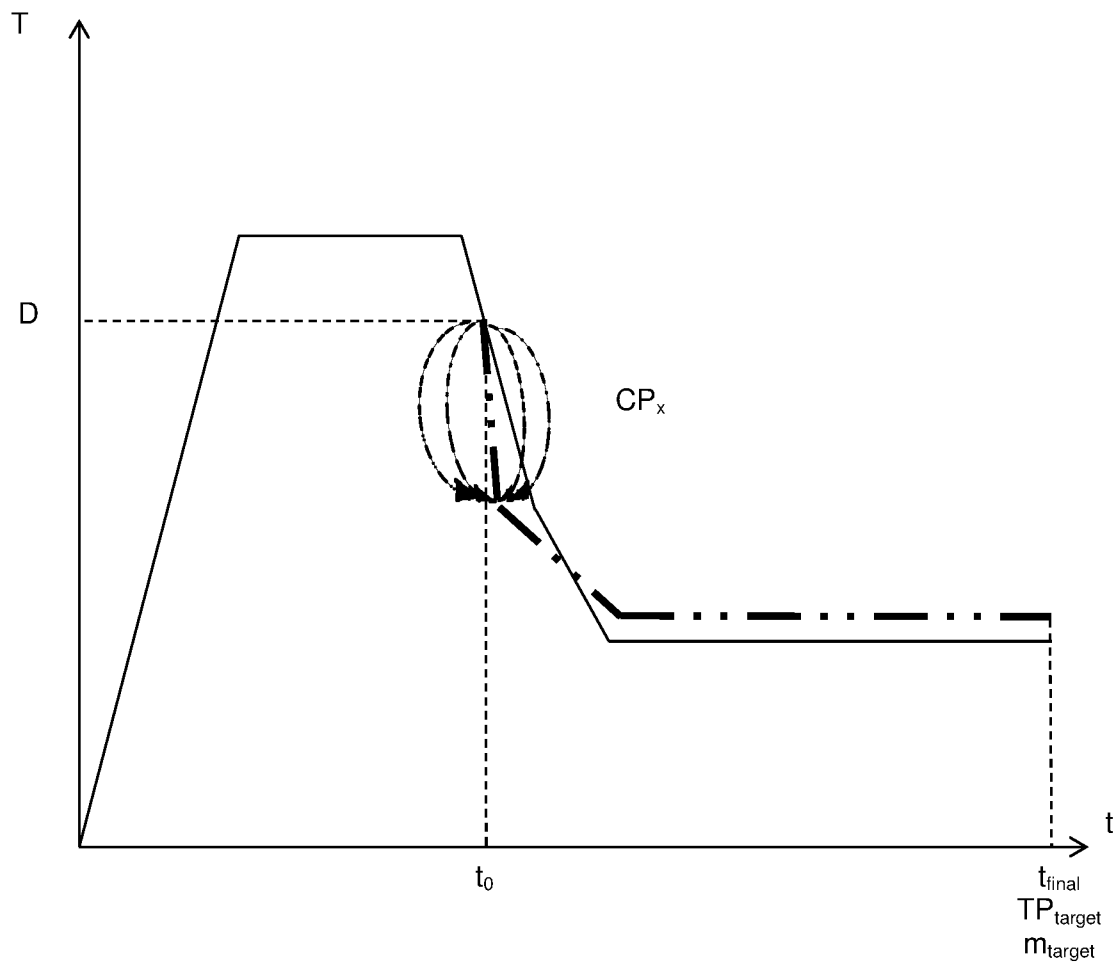
- 5 21. Method according to any one of claims 1 to 20, wherein the cooling system comprises at least one jet cooling, at least one cooling spray or at least both.
- 10 22. Method according to any one of claims 1 to 21, wherein T_{cooling} is the bath temperature when the cooling section is followed by a hot-dip coating section comprising a hot-dip bath.
23. Method according to claim 22, wherein the bath is based on aluminum or a bath based on zinc.
- 15 24. Method according to any one of claims 1 to 23, wherein T_{cooling} is the quenching temperature T_q .
25. Method according to any one of claims 1 to 24, wherein T_{cooling} is between 150 and 800°C.
- 20 26. A method according to any one of claims 1 to 25, wherein every time a new steel sheet enters into the heat treatment line, a new calculation step B.1) is automatically performed.
- 25 27. A method according to claim 26, wherein an adaptation of the cooling path is performed as the steel sheet entries into the cooling section of the heat treatment line on the first meters of the sheet.
- 30 28. A method according to any one of claims 1 to 15, wherein an automatic calculation is performed during the thermal treatment to check if any deviation had appeared.
- 35 29. A Computer program product comprising at least a metallurgical module, an optimization module and a thermal module cooperating together to calculate TP_{target} such modules comprising software instructions that when implemented by a computer implement the method according to claims 1 to 28.

1 / 4

Figure 1



2 / 4
Figure 2



3/4

Figure 3

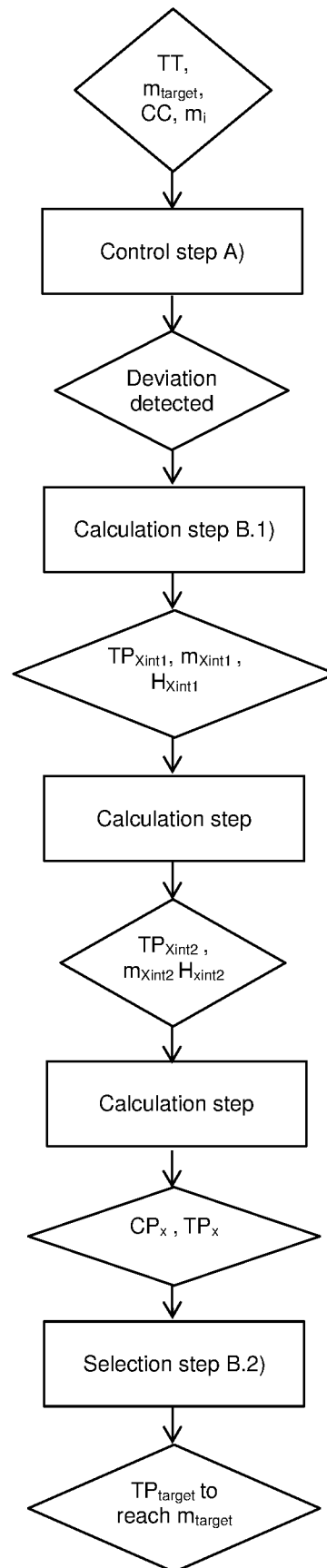


Figure 4

