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(54) **HOT-ROLLED STEEL & METHOD FOR MANUFACTURING HOT-ROLLED STEEL**
WARMGEWALZTER STAHL UND VERFAHREN ZU DESSEN HERSTELLUNG
ACIER LAMINÉ À CHAUD ET PROCÉDÉ DE FABRICATION D'ACIER LAMINÉ À CHAUD

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(73) Proprietor: **SSAB Technology AB**
101 21 Stockholm (SE)

(72) Inventors:
- **Liimatainen, Tommi**
  92130 Raahe (FI)
- **Hemmilä, Mikko**
  86400 Vihanti (FI)
- **Hirvi, Ari**
  90250 Oulu (FI)
- **Limnell, Teijo**
  00810 Helsinki (FI)
- **Saarinen, Tuomo**
  00810 Helsinki (FI)
- **Antola, Tuomas**
  92100 Raahe (FI)
- **Lehtikangas, Pasi**
  92100 Raahe (FI)
- **Kesti, Vili**
  90570 Oulu (FI)
- **Tihinen, Sakari**
  90440 Oulu (FI)
- **Martinmäki, Saija**
  92100 Raahe (FI)

(74) Representative: **Valea AB**
Box 1098
405 23 Göteborg (SE)

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Description

TECHNICAL FIELD

[0001] The present invention concerns high strength hot-rolled steel and a method for manufacturing such hot-rolled steel.

BACKGROUND OF THE INVENTION

[0002] Martensitic flat steel products have for many years been manufactured using a method comprising the steps of heating a steel slab to an austenitizing temperature, hot-rolling, re-heating, quenching and tempering, or alternatively, heating a steel slab to an austenitizing temperature, hot-rolling, direct quenching and tempering.

[0003] For example, European patent no. EP 2,576,848 discloses a method for producing a hot-rolled steel from a steel, whose composition as percentages by weight is C 0.075 - 0.12%, Si 0.1 - 0.8%, Mn 0.8 - 1.7%, Al 0.015 - 0.08%, P less than 0.012%, S less than 0.005%, Cr 0.2 - 1.3%, Mo 0.15 - 0.80%, Ti 0.01 - 0.05%, B 0.0005 - 0.003%, V 0.02 - 0.10%, Nb less than 0.3%, Ni less than 1%, Cu less than 0.5%, the remainder being iron and unavoidable impurities. The patent describes direct quenched martensitic sheet-like steels which are temper annealed. The hot-rolled steel is exceptionally temper-resistant after the direct quenching process, wherein by tempering, high-strength (i.e. $Rp_{0.2}$ of at least 890MPa) combined with good impact toughness (Charpy V (-20°C) =37J) and flangeability, as well as good weldability are achieved.

[0004] European patent application np. EP 2,949,775 A1 discloses an ultra-high durability steel plate having a low yield ratio, comprising the chemical elements in mass percentages of: C: 0.18-0.34%, Si: 0.10-0.40%, Mn: 0.50-1.40%, Cr: 0.20-0.70%, Mo: 0.30-0.90%, Nb: 0-0.06%, Ni: 0.50-2.40%, V: 0-0.06%, Ti: 0.002-0.04%, Al: 0.01-0.08%, B: 0.0006-0.0020%, N ¤0.0060%, O ¤0.0040%, Ca: 0-0.0045%, and the balance of Fe and other unavoidable impurities. A process of manufacturing the steel plate is also disclosed, wherein the heating temperature is 1080-1250 °C; the quenching temperature is 860-940 °C; and the tempering temperature is 150-350 °C.

[0005] Japanese patent application no. JP 2006206942A provides a method of manufacturing a high-tensile steel excellent in hydrogen embrittlement resistance, which is less likely to cause hydrogen embrittlement such as delayed fracture, weld delayed cracking, and sulphide corrosion cracking. The steel is composed of, in mass%, C: 0.02 to 0.25%, Si: 0.01 to 0.8%, Mn: 0.5 to 2.0%, Al: 0.005 to 0.1%, N: 0.0005 to 0.008%, P: 0.03% or less, S : 0.03% or less, optionally containing one or two or more of Cu, Ni, Cr, Mo, Nb, V, Ti, B, Ca, REM, Mg, and the balance being Fe and unavoidable impurities.

[0006] Such flat steel products may be used for applications, such as wear or structural applications, in which the steel must exhibit high strength in combination with sufficient hardness, bendability and impact toughness both in the as-produced steel products and in the HAZ (heat affected zone) area of welded steel products.

SUMMARY OF THE INVENTION

[0007] An object of the invention is to provide improved hot-rolled steel.

[0008] This object is achieved by hot-rolled steel having the features recited in claim 1,

[0009] By adding the alloying elements in the recited amounts, a combination of good base material toughness and strength properties can be achieved and any fracture occurring during a tensile test of a weld will occur as far as possible from the fusion line.

[0010] Carbon is needed to achieve high base material strength and the other elements listed above promote the strength of the weld so as to avoid softened zones in a welded seam which would "catch" the fracture. Manganese, molybdenum and vanadium also promote the strength of quenched and tempered steel.

[0011] From a toughness point of view, it is important to have a carbon content that is as low as possible. The amount of each element in the embodiments a) to d) provides a good combination of toughness and high strength.

[0012] Hot-rolled steel having the chemical composition given above and manufactured using the method described herein exhibits high strength (i.e. a yield strength ($Rp_{0.2}$) of at least 1100 MPa) along and transverse to a rolling direction and a tensile strength of at least 1120 MPa along and transverse to a rolling direction, good bendability (i.e. a minimum bending radius of 5.0 x thickness along and/or transverse to a rolling direction, preferably 4.0 x thickness along a rolling direction or more preferably 3.5 x thickness along a rolling direction and an impact toughness of at least 34 J/cm^2 and more, preferably an impact toughness of at least 50 J/cm^2 when a Charpy V notched specimen having a thickness of 5-10 mm is measured at -40°C longitudinally to the rolling direction, and good ductility (i.e. an A%-elongation of at least 8% along and transverse to the rolling direction, preferably of at least 10% or most preferably at least 12%). Mechanical properties are defined according to the testing instructions of standard ISO 10025-6.

[0013] Preferably, this combination of properties is achieved both in the as-produced hot-rolled quenched and tempered steel products and in the HAZ (heat affected zone) area of welded hot-rolled steel products (which are welded using a filler material that is designed for steels having a yield strength of at least 1100 MPa, preferably of at least 960 MPa, more preferably at least 900 MPa, most preferably of at least 890 MPa, such as X90 or preferably X96).

[0014] The prior art includes hot-rolled steel sheets having a yield strength ($Rp_{0.2}$) of at least 1100 MPa, although those prior art hot-rolled steel sheets do not have such good weldability or such good mechanical properties when welded.

[0015] The expression hot-rolled steel as used herein means a steel that is hot-rolled to be sheet-like, such as a hot-rolled heavy plate or preferably hot-rolled strip steel. The thickness of the hot-rolled strip steel may be 2 - 15 mm, preferably 2.5 - 10 mm. The thickness of the hot-rolled heavy plate may be 4 - 50 mm, preferably 5 - 25 mm. According to an embodiment of the invention the hot-rolled steel comprises 0.4-1.7 mass-% Cr, preferably 1.0 -1.7 mass-% Cr.

[0016] According to an embodiment of the invention the chemical composition contains both Ni and Cu, and the amount of Ni ≥ 0.33 x the amount of Cu, preferably the amount of Ni ≥ 0.5 x the amount of Cu so as to maintain high surface quality of the steel in hot-rolling. Furthermore, the alloying costs of the hot-rolled steel can be kept as low as possible while achieving the advantageous properties of the hot-rolled steel according to the present invention (since Nickel is an expensive alloying element). Nickel prevents Copper from melting under the scale that may be formed on the outer surfaces of the steel when it is annealed before hot-rolling and which comprises iron oxides and thereby prevents Copper from going into the grain boundaries, which can weaken the grain boundaries. Weakened grain boundaries can promote surface cracking and defects during the hot-rolling process.

[0017] According to an embodiment of the invention the chemical composition contains both Ni and Cu in a total amount of at least 0.5 mass-%, or at least 1.0 mass-%, or at least 1.2 mass-%.

[0018] According to an embodiment of the invention the hot-rolled steel has a tensile strength of at least 1120 MPa, or at least 1130 MPa, or at least 1200 MPa, and/or maximum 1250 MPa or maximum 1300 MPa, or maximum up to 1450 MPa along and/or transverse to the rolling direction.

[0019] According to an embodiment of the invention the hot-rolled steel iis used for metal active gas (MAG) welded with reinforcement, as defined in claim 13.

[0020] The t8/5 time is the time it takes for a weld seam and an adjacent heat-affected zone (HAZ) to cool from 800°C to 500°C. The expression "weld seam" means the total weld area (WM and HAZ). A t8/5 time lower than 5 seconds may adversely affect the toughness properties of the steel. A t8/5 time greater than 20 seconds may adversely affect the strength of the steel. The MAG-welded transversal tensile test specimen's fracture does not occur in the weld metal or fusion line and the fracture is moved ≥ 1 mm or ≥ 2 mm or ≥ 3 mm from the fusion line with or without reinforcement when using welding consumables having a tensile strength of 1100 MPa, preferably 960 MPa, more preferably 900 MPa, most preferably 890 MPa, and a t8/5 time of 8 - 12 seconds, preferably 6 - 18 seconds, more preferably 5-20 seconds..

[0021] According to the embodiment defined in claim 7 the hot-rolled steel has an elongation of at least 7%, preferably at least 8%, more preferably at least 9% when a tensile test is carried out across a weld seam of a welded hot-rolled steel product where the weld is longitudinal to the rolling direction. The hot-rolled steel is welded using welding consumables having a tensile strength of 1100 MPa, preferably 960 MPa, more preferably 900 MPa, most preferably 890 MPa, and a t8/5 time of 8 - 12 seconds, preferably 6 - 18 seconds, more preferably 5-20 seconds..

[0022] The present invention also concerns a method for manufacturing hot-rolled steel according to any of the embodiments of the invention, having the features recited in claim 8.

[0023] The method comprises the following steps carried out in the following order:

- heating a steel slab having a chemical composition as recited in claim 1 to an austenitizing temperature of 1000 - 1350 °C, preferably 1200 - 1350°C,
- hot-rolling such that a finishing rolling temperature is 760 - 1050°C, preferably 760 - 960°C,
- quenching to 300 °C or less, preferably 150°C or less, and

temper annealing at a temperature of 500 - 650 °C, if the tempering time is 1 hour or more, or temper annealing at a temperature of 500 - 750 °C, if the tempering time is less than 1 hour after said quenching step, whereby the microstructure of the hot-rolled steel before the temper annealing step contains at least 90% martensite, when said microstructure is examined in ¼ thickness and the content of ferrite and pearlite before the temper annealing step must be in total less than 10%

[0024] Quenching results in at least 90% martensite in the microstructure, preferably 95% martensite, and more preferably 99% martensite when the microstructure is examined in ¼ thickness.

[0025] It is beneficial to use such relatively high austenitizing temperatures because in strip rolling the final thickness is small and steel tends to cool down during rolling. By using higher heating temperatures, steel is warmer during strip rolling and rolling forces are smaller. Austenite grain refinement is also easier then. Higher austenitization temperatures also promote more uniform grain structure before rolling.

[0026] If very high temperatures (of more than 1350°C) are used there is a risk that large grain size will be obtained.

Furthermore, steel may oxidize aggressively and there may be a yield loss due to high scaling. Additionally, production costs will be increased.

[0027] The quenching step is preferably a direct quenching step, which is for example conducted a maximum of 15 seconds after the last hot-rolling pass. The cooling rate during quenching is typically 30 - 150 °C/s.

[0028] For maximizing total elongation in a direction transverse to the rolling direction, the method comprises the step of temper annealing at a temperature of 500 - 650 °C, more preferably 550 - 650 °C, whereby the tempering time is 1 hour or more, or temper annealing at a temperature of 500 - 750 °C, more preferably 550 - 750 °C, if the tempering time is less than 1 hour. Tempering time is the holding time after the steel has reached the tempering temperature. The temper annealing improves the impact toughness and elongation of the hot-rolled steel while maintaining its strength. When maximum total elongation is not required, the temper annealing step is carried out at a temperature of 150 - 499°C, more preferably 180 - 250°C with any tempering time used. The microstructure of the hot-rolled steel before the temper annealing step contains at least 90% martensite, preferably at least 95% martensite and more preferably at least 99% martensite when said microstructure is examined in ¼ thickness.

[0029] It should be noted that the temper annealing step may be conducted immediately after the quenching. Alternatively, one or more additional method steps may be carried out between the quenching step and the temper annealing step. For example, the quenched steel may be subjected to an acid pickling step and/or coiling and/or straightening.

[0030] The mechanical properties of the hot-rolled steel as produced and when welded are good because of the chemical composition of the steel and because the material is tempered at a relatively high temperature of at least 500°C, preferably of at least 550°C and more preferably of at least 580°C. If the tempering time is relatively short, i.e. less than 1 hour, (for example when induction tempering is used), the tempering temperature can be higher, for example 50°C higher or more. The maximum tempering temperature is 750°C.

[0031] According to an embodiment of the invention the temper annealing is preferably carried out in a furnace other than a bell-type furnace, i.e. the temper annealing step is preferably not carried out in a bell-type furnace but any other suitable type of furnace. A bell-type furnace is a batch furnace that consists of an insulated chamber with a steel shell and a heating system. Bell furnaces have removable covers called *bells,* which are lowered over the load and hearth using a crane. An inner bell is placed over the hearth and sealed to supply a protective atmosphere. An outer bell is lowered to provide the heat supply. If temper annealing is carried out in a bell-type furnace, the steel may typically be subjected to a temperature of 450-600°C for a long period of time since the temperature inside the insulated chamber rises and falls slowly, which may cause brittleness in some steels since atomic segregations may form at grain boundaries, which can weaken the steels and make them very fragile at room temperature.

[0032] According to an embodiment of the invention the method comprises the step of strip rolling the hot-rolled steel. The hot-rolled steel comprises a maximum of 0.005 mass-% Niobium and < 0.15 mass-% Carbon when the hot-rolled steel is strip rolled.

[0033] The hot-rolled steel comprises a minimum of 0.005 or 0.04 or 0.02 mass-% Niobium when the hot-rolled steel is not strip rolled. More than 0.06 mass-% Niobium has no effect or only a minor effect on the strength properties of the hot-rolled steel.

[0034] When direct quenched, the strip rolling as a process produces a more elongated austenite grain structure (flattened) compared to plate rolling, where the time for recrystallization is longer and recrystallization is easier. By using Niobium, the flattening ratio can be increased. To achieve the same flattening ratio as for strip rolling, the plate steel is often alloyed with Niobium. Flattening of austenite increases the strength and impact toughness of the steel.

[0035] When steel is reheated and quenched after hot-rolling, Niobium is needed to get high strength and impact strength. The minimum amount of Niobium required is then >0.005 mass-%, preferably >0.02 mass-%.

BRIEF DESCRIPTION OF THE DRAWINGS

[0036] The present invention will hereinafter be further explained by means of non-limiting examples with reference to the appended figures where;

Figure 1 shows a flow chart showing the steps of a method according to an embodiment of the invention, including the alternative to temper anneal at at temperature of 150-499°C falling outside the embodiment.

Figure 2 shows hardness profiles for material having a thickness of 8 mm over the weld tested from face side (i.e. the side at which welding took place) and the root side (i.e. the side opposite to the side at which welding took place), and

Figure 3 shows hardness profiles for material having a thickness of 4 mm over the weld tested from face side and the root side.

It should be noted that all features disclosed with reference to a hot-rolled steel according to the present invention also apply to a method according to the present invention, and vice versa.

DETAILED DESCRIPTION OF EMBODIMENTS

[0037] Figure 1 shows the steps of a method for manufacturing hot-rolled steel according to any of the embodiments of the invention having a chemical composition containing (in mass-%):

- C 0.10 - 0.2, preferably 0.10 - 0.18, more preferably 0.12 - 0.18,
- Si 0 - 0.7, preferably 0.03 - 0.50, more preferably 0.10 - 0.30,
- Mn 1.3 - 2.2, preferably 1.4 - 1.8, more preferably 1.4 - 1.7,
- Nb 0 - 0.06, preferably 0 - 0.04, more preferably 0 - 0.005,
- Ti 0 - 0.15, preferably 0 - 0.05 more preferably 0.005 - 0.02,
- V more than 0.03 and ≤ 0.25, preferably more than 0.10 and ≤ 0.20,
- Al 0.01 - 0.15, preferably 0.015 - 0.08,
- B 0.0005 - 0.010, preferably 0.0005 - 0.005, more preferably 0.001 - 0.003,
- Cr 0. 1 - 1.7, preferably 0.4 - 1.7 or 0.6 - 1.5, or more than 1.0 mass-%,
- Mo 0.15 - 0.8, preferably 0.2 - 0.5,
- Cu 0 - 1.5, preferably 0.1-1.0,
- Ni 0.3 - 2.5, preferably 0.7 - 1.7,
- P 0 - 0.015, preferably 0 - 0.009,
- S 0 - 0.008, preferably 0 - 0.004,
- Zr 0 - 0.2, preferably 0 - 0.01
- Ca 0 - 0.004, preferably 0.001 - 0.003,
- preferably N 0-0.01 mass-%, more preferably ≤ 0.006 mass-%.
- balance Fe and unavoidable impurities.

whereby:

a) when 0.10 < C < 0.11 then Mn ≥ 1.6 and V > 0.14 and Mo ≥ 0.5 (in mass-%),
b) when 0.11 < C < 0.125 then Mn ≥ 1.45 and V ≥ 0.13 and Mo ≥ 0.35 (in mass-%),
c) when 0.125 < C < 0.15, then Mn ≥ 1.35 and V ≥ 0.12 and Mo ≥ 0.20 (in mass-%),
d) when C ≥ 0.15 and V > 0.11, then Mn ≥ 1.3 and Mo ≥ 0.15 (in mass-%) or
when C ≥ 0.15 and V 0.03 - 0.11, then Mn > 1.3 and Mo > 0.15 and Nb > 0.02 and Cr+Cu+Ni >1.4 (in mass-%).

[0038] The method comprises the step of heating a steel slab having the chemical composition described above to an austenitizing temperature of 1000-1350 °C.

[0039] The thickness of the steel slab is, for example, 210 mm and it is preferably heated to an austenitizing temperature of 1200 - 1350°C, where it is kept until it is of adequately even warmth and the alloying elements have adequately dissolved into the matrix. Typically, this takes several hours. If the austenitizing temperature is below 1200 °C, there can be a danger that not all of the alloying elements will dissolve into the austenite, i.e. the austenite is not made homogenous and during the tempering, the precipitation hardening may remain at a low level. On the other hand, if the austenitizing temperature is higher than 1350 °C, this will result in an exceptionally large grain size of the austenite and increased oxidation of the slab surface. Annealing time in reheating is typically varied in the range of 2 - 4 hours, but, depending on the selected furnace technology and the thickness of the slab, it can also be longer than 4 hours or shorter than 2 hours.

[0040] After the heating step, hot-rolling is conducted, which may typically comprise a roughing step and a subsequent finish rolling step. The temperature of hot-rolling at the last pass is 760 - 1050°C. Preferably, the finishing rolling temperature at the last pass of the hot-rolling is 760 - 960°C. The end temperature of hot-rolling is preferably above 830 °C or more preferably at least 850°C so that rolling forces remain reasonable, and at the most 940 °C, and more preferably 920° at the most, wherein i.a. excellent surface quality is assured.

[0041] After hot-rolling, or strip rolling, the steel is quenched, i.e. cooled at an accelerated cooling rate, typically of 30 - 150 °C/s, using one step cooling for example, preferably at a maximum cooling rate of 120°C/s, in a suitable quenching medium, such as water or oil, to a temperature of 300 °C or less, or preferably 150°C or less, i.e. any temperature between room/ambient temperature and 300°C. If it is a strip product it is coiled at that temperature, i.e. at a coiling temperature of 300°C or less. Preferably, the quenching is direct quenching conducted a maximum of 15 seconds after the last hot-rolling pass.

[0042] This quenching gives the steel its exceptionally good mechanical properties including good impact toughness combined with good bendability. Preferably, the end temperature of quenching is a maximum of 150°C, because, in this case, after quenching, a steel product with good flatness is achieved.

[0043] The quenched steel is subsequently subjected to temper annealing at a temperature of 500 - 650 °C if the tempering time is 1 hour or more, or temper annealing at a temperature of 500 - 750 °C if the tempering time is less than 1 hour. If the tempering temperature is 400 - 750°C then the temper annealing is typically carried out in a furnace other than a bell-type furnace so as to avoid the risk of adversely affecting the strength and toughness properties of the steel. However, if the tempering temperature is 150 - 250°C then the tempering annealing may also be carried out in a bell-type furnace without adversely affecting the strength and toughness properties of the steel and to minimize production costs. Tempering at annealing temperatures of 250 - 400°C is not recommended due to low temperature tempering embrittlement if good toughness properties are required. Typically, higher temperatures promote good total elongation values, and lower tempering temperatures promote higher strength properties.

[0044] A suitable tempering treatment is defined by the formula $P = T^*(20+\log t)$, where the temperature T is in °K and the time is in hours. The Larsen Miller parameter, P, is between 15 - 19.5, and preferably 16 - 18.

[0045] The temper annealing step may be carried out on quenched steel, such as steel sheet cut from a coil, or on a steel sheet that is continuously unwound from a coil, or a heavy plate. In the case of a strip product, the temper annealing step may alternatively be carried out on a whole coil, for example in a bell type furnace.

[0046] The microstructure of the hot-rolled steel before the temper annealing step contains at least 90% martensite, preferably at least 95% martensite and more preferably at least 99% martensite when the microstructure is examined in ¼ thickness. The majority of the microstructure will be martensite although it may contain some bainite. The content of ferrite and pearlite before the temper annealing step must be in total less than 10%, preferably less than 5%.

[0047] Manganese content as a percentage by weight is 1.1 - 2.2 mass-% in order to assure good hardenability in the weld metal and HAZ of welded hot-rolled steel. Manganese also promotes hardenability of the base material during the quenching step. The expression "weld metal" is intended to mean the part of the weld seam that consists mainly of filler material.

[0048] The maximum Manganese content should be set according the equation so as to prevent excessive segregations and ensure good impact strength:

maximum Manganese content (in mass-%) = 2.7- 5*Carbon content (in mass-%).

[0049] Molybdenum precipitates in temper annealing, which decreases the lowering of strength caused by tempering treatment and thus helps in achieving high strength. Additionally, Molybdenum is used *inter alia* to prevent the brittleness of steel by slowing infiltration of *inter alia* Phosphorus into the grain boundaries during temper annealing. Molybdenum also efficiently increases the hardenability of the base material and ensures good strength properties of welded seams of welded hot-rolled steel.

[0050] It has been found that Niobium may decrease the bendability of a hot-rolled steel if it is present in a large amount. The use of Niobium as an alloying element is however of advantage in achieving adequate strength and impact toughness in hot-rolled steel. Niobium promotes smaller grain size in steel, which results in better properties of the steel. Niobium may be needed, especially in the case of heavy plate, to enable smaller amounts of other alloying elements that promote good strength and toughness properties to be used. In the case of a direct quenched strip product, the steel can be also made without using Niobium. Niobium is therefore an optional alloying element in the hot-rolled steel according to the present invention, the content of which should be limited to 0.06 mass-%, preferably to 0.04 mass-%, and more preferably to 0.005 mass-%, wherein the best possible bendability properties for the hot-rolled steel are assured.

[0051] Titanium is an optional alloying element in the hot-rolled steel according to the present invention, which may be required for binding Nitrogen in the steel, and so that Boron functions efficiently as an improver of hardenability and does not form Boron nitrides. Titanium is used, because it works more reliably with quenched steel than Aluminium. The Titanium content is 0 - 0.15 mass-%, preferably 0 - 0.05 mass-% and more preferably 0.005 - 0.02 mass-%. Titanium nitrides exhibit grain growth in the heat affected zone of a weld and improve the toughness properties of a welded seam. On the other hand, at contents higher than 0.02 mass-%, the amount of relatively large-sized Titanium nitrides, TiN may increase, which is detrimental in terms of the impact toughness and bending properties of the hot-rolled steel. The Ti/N ratio of the hot-rolled steel is preferably in the range 3 - 4. However, larger Titanium contents up to 0.15 mass-% may be used to increase strength in the as-tempered condition.

[0052] Vanadium content in the hot-rolled steel according to the present invention must be more than 0.1 mass-% and ≤ 0.25 mass-%, preferably more than 0.10 and ≤ 0.20 mass-%, or at least 0.11 mass-% Vanadium, or at least 0.12 mass-% Vanadium, or at least 0.13 mass-% Vanadium, or at least 0.14 mass-% Vanadium in order to assure high strength. It has however been found that a too high amount of Vanadium is detrimental to the impact toughness of the quenched and tempered steel. The amount of Vanadium should not therefore exceed 0.25 mass-%. Vanadium has a strong precipitation strengthening effect after tempering and is needed to achieve high strength both in base metal and in the HAZ.

[0053] Aluminium is used to condense steel, i.e. to bind oxygen from the steel. The Aluminium content is 0.01 - 0.15 mass-%, preferably 0.015 - 0.08 mass-% to prevent excessive formation of aluminium oxides.

[0054] Boron is an effective alloying element that promotes hardenability of the steel in quenching. It is an essential alloying element in this invention since it promotes strength and hardness properties in the weld metal and heat-affected zone (HAZ). During welding, Boron moves from the base material to the weld metal, thereby increasing the hardness of the weld metal. This ensures that fracture does not occur in the weld metal or fusion line. Fracture can be moved as far as possible away from the fusion line towards the base material in high static loads. The Boron content is 0.0005 - 0.010 mass-%, preferably 0.0005 - 0.005 mass-% and more preferably 0.001 - 0.003 mass-%. A Boron content of at least 0.0005 mass-% promotes hardenability of the base material and of the HAZ, ensuring good strength properties. On the other hand, a Boron content of more than 0.005 mass-% is worthless as regards the hardenability of the base material and the HAZ. When the Boron content is more than 0.001 mass-%, it ensures matching strength properties of the weld and fracture location as previously described. A Boron content of more than 0.010 mass-% can be detrimental for mechanical properties of the steel.

[0055] The Chromium content of hot-rolled steel according to the present invention is 0. 1 - 1.7 mass-%, preferably 0.4 - 1.7 or 0.6 - 1.5 mass-%, or more than 1.0 mass-% in order to achieve high strength and good hardenability both in the hot-rolled steel as produced and in the HAZ of a welded hot-rolled steel product. Chromium also promotes tempering resistance.

[0056] According to an embodiment of the invention the chemical composition of hot-rolled steel according to the present invention contains both Ni and Cu in a total amount of at least 0.5 mass-%, or at least 1.0 mass-%, or at least 1.2 mass-%. Copper is an optional alloying element. It can be used in an amount up to 1.5 mass-%, preferably 0.1-1.0 mass-% in order to increase the strength or improve the weather resistance of the hot-rolled steel.

[0057] According to an embodiment of the invention the chemical composition contains both Ni and Cu, and the amount of Ni $\geq$ 0.33 x the amount of Cu, preferably the amount of Ni $\geq$ 0.5 x the amount of Cu. Cr+Cu+Ni is between 0.4 - 5.7, preferably between 1.4 - 3.5 and more preferably between 2 - 3.

[0058] Nickel is an essential alloying element in the hot-rolled steel according to the present invention and it improves the toughness of the heat-affected zones and the weld metal of welded seams and it also improves the surface quality of the hot-rolled steel containing Copper but may, under some circumstances, slightly decrease the impact toughness of the tempered steel.

[0059] Phosphorus weakens the impact toughness of quenched and tempered steel and the Phosphorus content should therefore be limited to a maximum of 0.015 mass-%, preferably to a maximum of 0 - 0.009 mass-%.

[0060] Sulphur content is limited to a maximum of 0.008 mass-%, preferably to a maximum of 0.004 mass-%, to assure good impact toughness and formability in the hot-rolled steel according to the present invention.

[0061] Zirconium is an optional alloying element that may replace Niobium if needed. The Zirconium content can be between 0 - 0.2 mass-%, preferably 0 - 0.01 mass-%.

[0062] Calcium is an optional alloying element that may be used to modify the morphology of inclusions in the steel. The Calcium content can be between 0 - 0.004 mass-%. If the amount of Calcium exceeds 0.004 mass-% the inclusions in the steel may be too large, which may adversely affect the physical properties of the steel.

[0063] The hot-rolled steel has a tensile strength of at least 1120 MPa and up to 1450 MPa.

[0064] According to an embodiment of the invention the hot-rolled steel has an A%-elongation of at least 8% (i.e. permanent elongation of length, expressed in percent of length) or even of at least 10% or at least 12% along and transverse to the rolling direction. The hot-rolled steel has such an elongation in its as-produced condition. The hot-rolled steel also has an elongation of at least 7%, preferably at least 8%, more preferably at least 9% when a tensile test is carried out across a weld seam of a welded hot-rolled steel product where the weld is longitudinal to the rolling direction.

[0065] According to an embodiment of the invention the hot-rolled steel an impact toughness of at least 34 J/cm^2 and more preferably an impact toughness of at least 50 J/cm^2 when a Charpy V notched specimen having a thickness of 5-10 mm is measured at -20°C and more preferably at -40°C longitudinally and transverse to the rolling direction. The hot-rolled steel has such an impact strength in its as-produced condition.

[0066] The mechanical properties of the hot-rolled steel cited in this document were determined in accordance with the testing instructions of standard ISO 10025-6:2004.

[0067] According to an embodiment of the invention the hot-rolled steel is metal active gas (MAG) welded with our without reinforcement, using a V- or Y-groove welding method, whereby a first pass is welded from a bottom or top side, preferably from a bottom side, and other passes from a top side, using welding consumables having a tensile strength of 1100 MPa, preferably 960 MPa, more preferably 900 MPa, most preferably 890 MPa, and a t8/5 time of 8 - 12 seconds, preferably 6 - 18 seconds, more preferably 5-20 seconds, which may be determined by welding the hot-rolled steel and measuring the time it takes for the weld seam and the adjacent heat-affected zone (HAZ) to cool from 800°C to 500°C.

[0068] According to an embodiment of the invention the hot-rolled steel has a minimum bending radius of 5.0 x thickness or more preferably a minimum bending radius of 4.0 x thickness or more preferably a minimum bending radius of 3.5 x thickness longitudinally and transverse to the rolling direction. With a plate thickness of 7 mm or more the steel has a minimum bending radius of 5.0 x thickness or preferably a minimum bending radius of 4.0 x thickness or more preferably a minimum bending radius of 3.5 x thickness longitudinally to the rolling direction, and a minimum bending radius of 5.0 x thickness transverse to the rolling direction.

[0069] The hot-rolled steel according to the present invention is suitable for applications, such as wear or structural applications, in which the steel must exhibit high strength in combination with sufficient hardness, bendability and impact toughness both in the as-produced products and in the HAZ (heat affected zone) of welded hot-rolled steel products. For example, the hot-rolled steel according to the present invention may be used to produce any component for construction, mining, material-handling, earth-moving, pile driving, snow-plowing, landscaping or rock drilling equipment. The hot-rolled steel may for example be used to produce a lifting boom for an excavator or crane.

TEST RESULTS

[0070] Tests were conducted using the steels having the chemical compositions presented in Table 1 below. The amount of each element is given in mass-%, the balance being Fe and unavoidable impurities other than Nitrogen. It should be noted that Nitrogen may also be considered to be an unavoidable impurity. The amount of Nitrogen is however given in Table 1 along with the intentionally added alloying elements. The amount of Nitrogen is in the range of 0-0.01 mass-%.

[0071] It should be noted that the compositions labelled "INV" in Table 1 are steels that have the chemical composition and the physical properties of steel according to the present invention and which have been manufactured using a method according to the present invention. Comparative examples that do not have the chemical composition or the physical properties of steel according to the present invention, or which have not been manufactured using a method according to the present invention are labelled "REF" in Table 1.

Table 1: Chemical compositions

Comp.	C	Si	Mn	P	S	Al	Nb	V	Cu	Cr	Ni	N	Mo	Ti	Ca	B	INV/ REF
A1	0.13	0.20	1.5	0.01	0.001	0.05	0.00	0.15	0.4	1.3	1.0	0.004	0.4	0.01	0.002	0.001	**INV**
B	0.14	0.18	1.5	0.01	0.001	0.05	0.00	0.15	0.5	1.3	2.0	0.004	0.1	0.01	0.002	0.001	REF
C	0.17	0.19	1.5	0.01	0.001	0.05	0.04	0.05	0.5	0.7	1.0	0.004	0.4	0.01	0.002	0.001	INV
A2	0.13	0.20	1.5	0.01	0.002	0.05	0.00	0.15	0.5	1.4	1.0	0.004	0.4	0.01	0.003	0.002	INV
A3	0.13	0.18	1.5	0.01	0.002	0.06	0.00	0.15	0.4	1.3	1.0	0.004	0.4	0.01	0.003	0.001	INV
D	0.17	0.30	1.5	0.01	0.001	0.05	0.00	0.04	0.4	0.7	1.0	0.003	0.4	0.02	0.001	0.000	REF
E	0.13	0.19	1.5	0.01	0.001	0.05	0.00	0.04	0.4	0.7	1.5	0.003	0.4	0.02	0.001	0.000	REF
F	0.17	0.19	1.5	0.01	0.001	0.06	0.00	0.04	0.4	0.7	1.0	0.003	0.4	0.02	0.001	0.001	REF
G	0.18	0.03	1.5	0.01	0.001	0.05	0.00	0.04	0.4	1.0	1.0	0.003	0.4	0.02	0.001	0.001	REF

[0072] Steels having the chemical compositions presented in Table 1 were hot-rolled to an end thickness of 4 mm, 6 mm and 8 mm. Hot-rolling was performed in a hot strip rolling line and hot-rolled strips were directly quenched after rolling before coiling. Depending on the type of tempering furnace used, the tempering was carried out before or after a cut-to-length process. If the tempering was performed in bell type furnace (tempering code "C" in Table 2 below), then the cut-to-length processing for quenched strips was carried out after tempering. In the case of sheet tempering (tempering code "S" in Table 2), the cut-to-length processing was carried out before the tempering annealing. Depending on the tempering method, the holding time during tempering varied between 15 - 720 minutes.

[0073] More specific manufacturing parameters are presented in Table 2.

Table 2: Process parameters

composition	process	tempering	thickness	furnT	FRT	CT	T	t	I NV/REF
code	code	code	mm	°C	°C	°C	°C	min	
A1	**R02**	**S600**	8.0	1280	856	50	600	30	INV
B	**R04**	**S600**	8.0	1280	862	50	600	30	REF
c	**R06**	**S560**	8.0	1280	878	50	560	30	INV
A2	**R12**	**S600**	4.0	1278	924	50	600	15	INV
A2	**R13**	**S585**	8.0	1267	871	50	585	15	INV
A2	**R13**	**S600**	8.0	1267	871	50	600	15	INV
A3	**R14**	**S585**	6.0	1279	897	50	585	15	INV
A3	**R14**	**S600**	6.0	1279	897	50	600	15	INV
A2	**R16**	**S585**	4.0	1279	917	50	585	15	INV
A2	**R16**	**S600**	4.0	1279	917	50	600	15	INV
D	**B05**	**C420**	6.0	1250	919	100	420	720	REF
A1	**B09**	**C200**	8.0	1250	891	100	200	720	REF
E	**B10**	**C600**	6.0	1250	876	100	600	240	REF
F	**B12**	**C450**	6.0	1250	897	100	450	540	REF
G	**B14**	**C450**	6.0	1250	918	100	450	540	REF
D	**B15**	**C600**	6.0	1250	917	100	600	240	REF

where: furnT = reheat temperature before hot-rolling
FRT = finishing rolling temperature
CT = coiling temperature
T = tempering temperature
t = tempering time

and the process code indicates the geographical location at which each process was carried out.

[0074] Test results from mechanical tests and bending tests are presented in Table 3. Steels according to invention have a mechanical properties as stipulated in claim 1.

[0075] Bending tests were carried out using three-point bending with samples having an area of 300 x 300 mm^2. Samples were bent to an angle of 90° with one press and all samples were bent into a Z-shape so that both the upper and lower surfaces of the samples were tested. Mechanical properties and bendability of the samples were tested both longitudinally with respect to the rolling direction, and transversely with respect to the rolling direction.

Table 3: Physical properties

composition code	rolling code	tempering code	thickness mm	test direction T/L	**Rp0.2** MPa	**Rm** MPa	**A%** %	**T_test** °C	**CV** J	**CV** J/cm2	**Bendability** Ri/t	INV/REF
A1	**R02**	**S600**	8.0	T	1151	1188	13.6	-40	33	55.0	4.5	INV
A1	**R02**	**S600**	8.0	L	1170	1180	15.0	-40	46	76.7	2.8	INV
B	**R04**	**S600**	8.0	T	1096	1128	14.7	-40	28	46.7	4.0	REF
B	**R04**	**S600**	8.0	L	1108	1119	15.4	-40	35	58.3	2.8	REF
C	**R06**	**S560**	8.0	T	1158	1196	13.3	-40	23	38.3	3.5	INV
C	**R06**	**S560**	8.0	L	1171	1185	14.2	-40	42	70.0	2.8	INV
A2	**R12**	**S600**	4.0	T	1111	1166	13.9	-40	10	50.0	2.0	INV
A2	**R12**	**S600**	4.0	L	1117	1170	15.1	-40	15	75.0	2.3	INV
A2	**R13**	**S585**	8.0	T	1170	1204	14.0	-40	29	48.3	2.1	INV
A2	**R13**	**S585**	8.0	L	1155	1177	15.1	-40	46	76.7	2.8	INV
A2	**R13**	**S600**	8.0	T	1163	1196	14.0	-40	28	46.7	2.1	INV
A2	**R13**	**S600**	8.0	L	1151	1171	15.4	-40	47	78.3	2.5	INV
A3	**R14**	**S585**	6.0	T	1129	1173	14.5	-40	18	45.0	2.3	INV
A3	**R14**	**S585**	6.0	L	1118	1152	15.6	-40	30	75.0	2.7	INV
A3	**R14**	**S600**	6.0	T	1128	1171	14.2	-40	18	45.0	2.2	INV
A3	**R14**	**S600**	6.0	L	1115	1147	15.5	-40	32	80.0	2.3	INV
A2	**R16**	**S585**	4.0	T	1134	1178	14.6	-40	16	50.0	2.0	INV
A2	**R16**	**S585**	4.0	L	1134	1163	15.8	-40	24	75.0	2.8	INV
D	**B05**	**C420**	6.0	T	1182	1277	7.3	-40	17	42.5	3.2	REF
D	**B05**	**C420**	6.0	L	1125	1251	9.0	-40	21	52.5	3.2	REF
A1	**B09**	**C200**	8.0	T	1349	1551	6.7	-40	53	88.3	2.5	REF
A1	**B09**	**C200**	8.0	L	1327	1519	9.0	-40	79	131.7	3.4	REF
E	**B10**	**C600**	6.0	T	1098	1137	8.9	-40	27	67.5	2.2	REF
E	**B10**	**C600**	6.0	L	1023	1108	11.8	-40	35	87.5	2.3	REF

(continued)

composition code	rolling code	tempering code	thickness mm	test direction T/L	**Rp0.2** MPa	**Rm** MPa	**A%** %	**T_test** °C	**CV** J	**CV** J/cm2	**Bendability** Ri/t	INV/REF
F	**B12**	**C450**	6.0	T	1170	1257	7.9	-40	20	50.0	2.8	REF
F	**B12**	**C450**	6.0	L	1098	1229	8.9	-40	29	72.5	3.3	REF
G	**B14**	**C450**	6.0	T	1180	1265	7.0	-40	19	47.5	2.7	REF
G	**B14**	**C450**	6.0	L	1105	1234	9.9	-40	28	70.0	3.2	REF
D	**B15**	**C600**	6.0	T	1095	1143	8.7	-40	19	47.5	1.8	REF
D	**B15**	**C600**	6.0	L	1028	1132	11.3	-40	30	75.0	2.0	REF

Welding tests

[0076] Welding tests were carried out using a metal active gas (MAG) welding method and V- and Y -grooves. The welding consumables used were according to standard ENG 89 5 M21 Mn4Ni2.5CrMo (Commercial grade X96). The first pass was welded from bottom or top side, preferably from the bottom side, and others passes were welded from the top side. Welding consumables having a tensile strength of 960 MPa were used and t8/5 was varied between 6 - 18 seconds. Tensile tests across the weld showed that the weld had a yield strength of 1100 MPa (Rp0.2) and the fracture was located at the base metal (BM).

[0077] The target was to achieve a combination of strength and toughness properties which are as good as possible in the weld so that matching tensile properties can be achieved without losing toughness. In addition, the aim was to obtain a fracture in a static tensile test over the weld that is located as far as possible from the weld metal (WM) and fusion line (FL), which enables extremely good elongation to fracture values for the welded structure. The behaviour of a welded structure is predictable and safe when the fracture in static loading takes place as far as possible away from the WM and FL and the elongation to fracture is high. The inventors have found that steels according to the present invention can fulfill these requirements even if the yield strength for the base material is more than 1100 MPa. Usually, known steels with such a high strength have a fracture located over the weld (WM or FL) when a tensile test is performed, especially when un-matching welding consumables are used (the yield strength of un-matching welding consumables is typically less than 1100 MPa).

[0078] Table 4 shows the welding parameters that were used in the tests and the test results obtained. Steels according the invention have a fracture that is located at a distance from the weld (WM and/or FL) when a static load in a tensile test is set over the weld. It is surprising compared to known steels that such behaviour can be achieved with or even without reinforcement. Without reinforcement, the achievement of such behaviour is very innovative. Fracture location is labelled "BM" in Table 4 when the fracture is in the base material, "HAZ" when it occurs in the Heat Affected Zone, and "WM" when the fracture occurs in the Weld Metal.

Table 4: Welding results

Processing variables					Transverse tensile test on weld								Cha rpy V (5x10x55 mm)					INV/REF
					Without reinforcement				With reinforcement				J /-40°C (mea n of 3 tests)					
composition code	rolling code	tempering code	thickness mm	t8/5s	Rp0.2 MPa	Rm MPa	A%%	fracture location	Rp0.2 MPa	Rm MPa	A%%	fracture location	WM	FL	FL+1	FL+3	FL+5	
A1	R02	S600	8	12	1125	1201	11,8	BM	1140	1194	10,8	BM	18	≠	25	37	20	INV
B	R04	S600	8	12	1078	1130	11,2	BM	1080	1123	11,2	BM	16	19	31	33	19	REF
C	R05	S560	8	6	1154	1213	9,8	BM	1160	1204	9,6	BM	≠	18	31	18	17	INV
C	R05	S560	8	12	1140	1212	10,0	BM	1143	1201	10,3	BM	20	18	24	32	18	INV
C	R05	S560	8	18	1115	1207	10,5	BM	1135	1198	10,4	BM	22	19	26	34	15	INV
D	B05	C420	6	6	1128	1233	4,7	HAZ	1174	1275	8,4	BM	27	27	36	24	25	REF
D	B05	C420	6	12	1081	1185	4,0	WM	1157	1252	6,2	HAZ	31	33	49	32	28	REF
D	B05	C420	6	18	1067	1175	5,0	WM	1162	1248	5,5	HAZ	35	43	53	35	30	REF
F	B12	C450	6	12	1101	1208	5,1	WM	1162	1244	7,3	HAZ	31	30	33	53	28	REF
G	B14	C450	6	12	1106	1217	5,2	WM	1161	1247	5,7	HAZ	27	29	32	40	26	REF
A2	R12	S600	4	12	1107	1176	11,7	BM	1118	1190	11,6	BM	≠	≠	≠	≠	≠	INV

where t8/5 = cooling time from 800 °C to 500 °C in the welded seam
Impact toughness was measured using specimens having a thickness of 5 mm.

[0079] Figures 2 and 3 shows typical hardness profiles over the welded seam tested near the face side and the root side of the welded samples. It is surprising that steels according to the present invention can have a very smooth hardness profile over the weld and that there are no soft zones that could start to neck during a tensile test and thereby influence the location of the fracture. Normally, steels with a yield strength of 1100 MPa welded with un-matching welding consumables (X90 and/or X96) exhibit some softening in the HAZ and especially in the WM. Steel according to the invention can maintain good hardness in the HAZ but also have good hardness in the WM due to the diffusion of alloying elements promoting hardening (i.e. Boron). Low carbon content in the steels according to the invention (i.e. 0.1 - 0.20 mass-% Carbon) ensures that a weld has high toughness as well as good hardness.

[0080] Further modifications of the invention within the scope of the claims would be apparent to a skilled person.

Claims

1. Hot-rolled steel having a yield strength $Rp_{0.2}$ of at least 1100 MPa along and transverse to a rolling direction and a tensile strength of at least 1120 MPa and up to 1450 MPa along and transverse to a rolling direction, **characterized in that:** it has an A%-elongation of at least 8% along and/or transverse to the rolling direction, an impact toughness of at least 34 J/cm^2 when a Charpy V notched specimen having a thickness of 5-10 mm is measured at -40°C longitudinally to the rolling direction, a minimum bending radius of 5.0 x thickness longitudinally and/or transverse to the rolling direction, and a chemical composition containing in mass-%:

   - C 0.10 - 0.2
   - Si 0 - 0.7
   - Mn 1.3 - 2.2
   - Nb 0 - 0.06
   - Ti 0 - 0.15
   - V more than 0.03 and ≤ 0.25
   - Al 0.01 - 0.15
   - B 0.0005 - 0.010
   - Cr 0.1 - 1.7
   - Mo 0.15 - 0.8
   - Cu 0 - 1.5
   - Ni 0.3 - 2.5
   - P 0 - 0.015
   - S 0 -0.008
   - Zr 0 - 0.2
   - Ca 0 - 0.004
   - N 0-0.01
   - balance Fe and unavoidable impurities,

   whereby:

   a) when 0.10 < C < 0.11 then Mn ≥ 1.60 and V > 0.14 and Mo ≥ 0.5
   b) when 0.11 ≤ C < 0.125 then Mn ≥ 1.45 and V ≥ 0.13 and Mo ≥ 0.35
   c) when 0.125 ≤ C < 0.15, then Mn ≥ 1.35 and V ≥ 0.12 and Mo ≥ 0.20, and
   d) when C ≥ 0.15 and V > 0.11, then Mn ≥ 1.3 and Mo ≥ 0.15 or

   when C ≥ 0.15 and V 0.03 - 0.11, then Mn > 1.3 and Mo > 0.15 and Nb > 0.02 and Cr+Cu+Ni >1.4.

2. Hot-rolled steel according to claim 1, whereby said chemical composition comprises 0.4-1.7 mass-% Cr, preferably 1.0 -1.7 mass-% Cr.

3. Hot-rolled steel according to claim 1 or 2, whereby said chemical composition contains both Ni and Cu, in a total amount of at least 0.5 mass-%, preferably at least 1 mass-%.

4. Hot-rolled steel according to any of the preceding claims, whereby the steel has an A%- elongation of at least 10% or more preferably at least 12% along and/or transverse to the rolling direction.

5. Hot-rolled steel according to any of the preceding claims, whereby the steel has an impact toughness of at least 50 J/cm^2 when a Charpy V notched specimen having a thickness of 5-10 mm is measured at -40°C longitudinally to the rolling direction.

6. Hot-rolled steel according to any of the preceding claims, whereby the steel has a minimum bending radius of 4.0 x thickness longitudinally and/or transverse to the rolling direction, more preferably a minimum bending radius of 3.5 x thickness longitudinally.

7. Hot-rolled steel according to any of the preceding claims, whereby the steel has an A%- elongation of at least 7%, preferably of at least 8% or more preferably at least 9% when a tensile test is carried out across a weld seam of a welded hot-rolled steel product where the weld is longitudinal to the rolling direction, whereby said hot-rolled steel is welded using metal active gas (MAG) welding with reinforcement, using a V- or Y-groove welding method, whereby a first pass is welded from a bottom or top side, preferably from a bottom side, and other passes from a top side, using welding consumables according to standard ENG 89 5 M21, commercial grade(s) X90 and/or X96, having a tensile strength of 890 MPa, preferably 960 MPa, more preferably 1100 MPa and a t8/5 of 5 - 20 seconds, preferably 6 - 18 seconds, or 8-12 seconds, whereby the welded steel has a fracture that is located at a distance of at least 1 mm from the fusion line.

8. Method for manufacturing hot-rolled steel according to claim 1, whereby the method comprises the following steps:

- heating a steel slab having a chemical composition according to claim 1 to an austenitizing temperature of 1000 - 1350 °C,
- hot-rolling such that a finishing rolling temperature is 760 - 1050°C,
- quenching to a temperature of 300 °C or less, and temper annealing at a temperature of 500 - 650 °C if the tempering time is 1 hour or more, or temper annealing at a temperature of 500 - 750 °C if the tempering time is less than 1 hour after said quenching step, whereby the microstructure of the hot-rolled steel before the temper annealing step contains at least 90 area-% martensite when said microstructure is examined in ¼ thickness, and the content of ferrite and pearlite before the temper annealing step must be in total less than 10 area-%.

9. Method according to claim 8, whereby the microstructure of the hot-rolled steel before said temper annealing step contains at least 95 area-% martensite and more preferably at least 99 area-% martensite when said microstructure is examined in ¼ thickness.

10. Method according to claim 8 or 9, whereby said quenching step is a direct quenching step.

11. Method according to any of claims 8-10, whereby the method comprises the step of strip rolling said hot-rolled steel and said hot-rolled steel comprises a maximum of 0.005 mass-% Niobium and < 0.15 mass-% Carbon.

12. Method according to any of claims 8-10, whereby said hot-rolled steel comprises a minimum of 0.005 mass-% Niobium, preferably a minimum of 0.02 mass-% Niobium when the hot-rolled steel is not strip rolled.

13. Use of a hot-rolled steel according to any of claims 1-7 for metal active gas (MAG) welding with reinforcement, using a V- or Y-groove welding method, whereby a first pass is welded from a bottom or top side, preferably from a bottom side, and other passes from a top side, using welding consumables according to standard ENG 89 5 M21, commercial grade(s) X90 and/or X96, having a tensile strength of 1100 MPa, preferably 960 MPa, more preferably 900 MPa, most preferably 890 MPa, and a t8/5 time of 8 - 12 seconds, preferably 6 - 18 seconds, more preferably 5-20 seconds, wherein the t8/5 time is the time it takes for the total weld area to cool from 800°C to 500°C , whereby the welded steel has a fracture that is located at a distance of at least 1 mm from the fusion line.

Patentansprüche

1. Warmgewalzter Stahl mit einer Streckgrenze $Rp_{0,2}$ von mindestens 1100 MPa entlang und quer zu einer Walzrichtung und einer Zugfestigkeit von mindestens 1120 MPa und bis zu 1450 MPa entlang und quer zu einer Walzrichtung, **dadurch gekennzeichnet, dass**: er eine A%-Dehnung von mindestens 8 % entlang und/oder quer zu der Walzrichtung, eine Kerbschlagzähigkeit von mindestens 34J/cm^2, wenn eine Probe mit einer V-Kerbe nach Charpy mit einer Dicke von 5-10 mm bei -40 °C längs zu der Walzrichtung gemessen wird, einen minimalen Biegeradius von

5,0 x Dicke längs und/oder quer zu der Walzrichtung und eine chemische Zusammensetzung aufweist, die in Masse-% enthält:

- C 0,10-0,2
- Si 0-0,7
- Mn 1,3-2,2
- Nb 0-0,06
- Ti 0-0,15
- V mehr als 0,03 und ≤ 0,25
- Al 0,01-0,15
- B 0,0005-0,010
- Cr 0,1-1,7
- Mo 0,15-0,8
- Cu 0-1,5
- Ni 0,3-2,5
- P 0-0,015
- S 0-0,008
- Zr 0-0,2
- Ca 0-0,004
- N 0-0,01
- Rest Fe und unvermeidbare Verunreinigungen,

wobei:

a) wenn 0,10 < C < 0,11 dann Mn ≥ 1,60 und V > 0,14 und Mo ≥ 0,5
b) wenn 0,11 ≤ C < 0,125 dann Mn ≥ 1,45 und V ≥ 0,13 und Mo ≥ 0,35
c) wenn 0,125 ≤ C < 0,15 dann Mn ≥ 1,35 und V ≥ 0,12 und Mo ≥ 0,20 und
d) wenn C ≥ 0,15 und V > 0,11 dann Mn ≥ 1,3 und Mo ≥ 0,15 oder

wenn C ≥ 0,15 und V 0,03-0,11 dann Mn > 1,3 und Mo > 0,15 und Nb > 0,02 und Cr+Cu+Ni > 1,4.

2. Warmgewalzter Stahl nach Anspruch 1, wobei die chemische Zusammensetzung 0,4-1,7 Masse-% Cr, vorzugsweise 1,0-1,7 Masse-% Cr umfasst.

3. Warmgewalzter Stahl nach Anspruch 1 oder 2, wobei die chemische Zusammensetzung sowohl Ni als auch Cu in einer Gesamtmenge von mindestens 0,5 Masse-%, vorzugsweise von mindestens 1 Masse-% enthält.

4. Warmgewalzter Stahl nach einem der vorstehenden Ansprüche, wobei der Stahl eine A%-Dehnung von mindestens 10 % oder besonders bevorzugt von mindestens 12 % entlang und/oder quer zu der Walzrichtung aufweist.

5. Warmgewalzter Stahl nach einem der vorstehenden Ansprüche, wobei der Stahl eine Kerbschlagzähigkeit von mindestens 50J/cm^2 aufweist, wenn eine Probe mit einer V-Kerbe nach Charpy mit einer Dicke von 5-10 mm bei -40 °C längs zu der Walzrichtung gemessen wird.

6. Warmgewalzter Stahl nach einem der vorstehenden Ansprüche, wobei der Stahl einen minimalen Biegeradius von 4,0 x Dicke längs und/oder quer zu der Walzrichtung, besonders bevorzugt einen minimalen Biegeradius von 3,5 x Dicke längs aufweist.

7. Warmgewalzter Stahl nach einem der vorstehenden Ansprüche, wobei der Stahl eine A%-Dehnung von mindestens 7 %, vorzugsweise von mindestens 8 % oder besonders bevorzugt von mindestens 9 % aufweist, wenn ein Zugversuch quer über eine Schweißnaht eines geschweißten, warmgewalzten Stahlprodukts ausgeführt wird, wo die Schweißung längs zu der Walzrichtung verläuft, wobei der warmgewalzte Stahl durch Anwenden von Metall-Aktivgas-Schweißen (MAG-Schweißen) mit Verstärker geschweißt wird, durch Anwenden eines Schweißverfahrens mit V- oder Y-Naht, wobei eine erste Lage ausgehend von einer Unter- oder Oberseite geschweißt wird, vorzugsweise von einer Unterseite, und weitere Lagen ausgehend von einer Oberseite, unter Verwendung von Schweißzusätzen gemäß der Norm ENG 89 5 M21, Handelssorte(n) X90 und/oder X96, mit einer Zugfestigkeit von 890 MPa, vorzugsweise 960 MPa, besonders bevorzugt 1100 MPa und einer t8/5 von 5-20 Sekunden, vorzugsweise 6-18 Sekunden oder 8-12 Sekunden, wobei der geschweißte Stahl einen Bruch aufweist, der sich in einem Abstand von mindestens 1 mm von der Schmelzlinie befindet.

8. Verfahren zur Herstellung von warmgewalztem Stahl nach Anspruch 1, wobei das Verfahren die folgenden Schritte umfasst:

- Erhitzen einer Stahlbramme mit einer chemischen Zusammensetzung nach Anspruch 1 auf eine Austenitisierungstemperatur von 1000-1350 °C,
- Warmwalzen, sodass eine abschließende Walztemperatur 760-1050 °C beträgt,
- Härten auf eine Temperatur von 300 °C oder weniger und Spannungsarmglühen bei einer Temperatur von 500-650 °C, wenn die Anlasszeit 1 Stunde oder mehr beträgt, oder Spannungsarmglühen bei einer Temperatur von 500-750 °C, wenn die Anlasszeit weniger als 1 Stunde beträgt, nach dem Härtungsschritt, wobei die Mikrostruktur des warmgewalzten Stahls vor dem Schritt des Spannungsarmglühens mindestens 90 Flächen-% Martensit enthält, wenn die Mikrostruktur in einer ¼-Dicke untersucht wird, und der Gehalt von Ferrit und Pearlit vor dem Schritt des Spannungsarmglühens insgesamt weniger als 10 Flächen-% betragen muss.

9. Verfahren nach Anspruch 8, wobei die Mikrostruktur des warmgewalzten Stahls vor dem Schritt des Spannungsarmglühens mindestens 95 Flächen-% Martensit und besonders bevorzugt mindestens 99 Flächen-% Martensit enthält, wenn die Mikrostruktur in einer ¼-Dicke untersucht wird.

10. Verfahren nach Anspruch 8 oder 9, wobei der Härtungsschritt ein Direkthärtungsschritt ist.

11. Verfahren nach einem der Ansprüche 8-10, wobei das Verfahren den Schritt des Bandwalzens des warmgewalzten Stahls umfasst und der warmgewalzte Stahl höchstens 0,005 Masse-% Niob und < 0,15 Masse-% Kohlenstoff umfasst.

12. Verfahren nach einem der Ansprüche 8-10, wobei der warmgewalzte Stahl mindestens 0,005 Masse-% Niob, vorzugsweise mindestens 0,02 Masse-% Niob umfasst, wenn der warmgewalzte Stahl nicht bandgewalzt wird.

13. Verwendung eines warmgewalzten Stahls nach einem der Ansprüche 1-7 zum Metall-Aktivgas-Schweißen (MAG-Schweißen) mit Verstärker, durch Anwenden eines Schweißverfahrens mit V- oder Y-Naht, wobei eine erste Lage ausgehend von einer Unter- oder Oberseite geschweißt wird, vorzugsweise von einer Unterseite, und weitere Lagen ausgehend von einer Oberseite, unter Verwendung von Schweißzusätzen gemäß der Norm ENG 89 5 M21, Handelssorte(n) X90 und/oder X96, mit einer Zugfestigkeit von 1100 MPa, vorzugsweise 960 MPa, besonders bevorzugt 900 MPa, am meisten bevorzugt 890 MPa, und einer t8/5 von 8-12 Sekunden, vorzugsweise 6-18 Sekunden, besonders bevorzugt 5-20 Sekunden, wobei die t8/5-Zeit jene Zeit ist, die es braucht, damit die gesamte Schweißfläche von 800 °C auf 500 °C abkühlt, wobei der geschweißte Stahl einen Bruch aufweist, der sich in einem Abstand von mindestens 1 mm von der Schmelzlinie befindet.

Revendications

1. Acier laminé à chaud présentant une limite d'élasticité $Rp_{0,2}$ d'au moins 1100 MPa longitudinalement et transversalement à une direction de laminage et une résistance à la traction d'au moins 1120 MPa et jusqu'à 1450 MPa longitudinalement et transversalement à une direction de laminage, **caractérisé en ce que :** il présente un allongement à la rupture d'au moins 8 % longitudinalement et/ou transversalement à la direction de laminage, une résistance au choc d'au moins 34J/cm^2 lorsqu'une éprouvette Charpy entaillée en V présentant une épaisseur de 5 à 10 mm est mesurée à -40 °C longitudinalement à la direction de laminage, un rayon de courbure minimum de 5,0 fois l'épaisseur longitudinalement et/ou transversalement à la direction de laminage, et une composition chimique contenant en % en masse :

- C 0,10 - 0,2
- Si 0 - 0,7
- Mn 1,3 - 2,2
- Nb 0 - 0,06
- Ti 0 - 0,15
- V supérieur à 0,03 et ≤ 0,25
- Al 0,01 - 0,15
- B 0,0005 - 0,010

- Cr 0,1 - 1,7
- Mo 0,15 - 0,8
- Cu 0 - 1,5
- Ni 0,3 - 2,5
- P 0 - 0,015
- S 0 - 0,008
- Zr 0 - 0,2
- Ca 0 - 0,004
- N 0 - 0,01
- le reste en fer et impuretés inévitables,

selon lequel :

a) lorsque 0,10 < C < 0,11 alors Mn ≥ 1,60 et V > 0,14 et Mo ≥ 0,5
b) lorsque 0,11 ≤ C < 0,125 alors Mn ≥ 1,45 et V ≥ 0,13 et Mo ≥ 0,35
c) lorsque 0,125 ≤ C < 0,15, alors Mn ≥ 1,35 et V ≥ 0,12 et Mo ≥ 0,20, et
d) lorsque C ≥ 0,15 et V > 0,11, alors Mn ≥ 1,3 et Mo ≥ 0,15 ou

lorsque C ≥ 0,15 et V 0,03 - 0,11, alors Mn > 1,3 et Mo > 0,15 et Nb > 0,02 et Cr + Cu + Ni > 1,4.

2. Acier laminé à chaud selon la revendication 1, selon lequel ladite composition chimique comprend 0,4 - 1,7 % en masse de Cr, préférentiellement de 1,0 à 1,7 % en masse de Cr.

3. Acier laminé à chaud selon la revendication 1 ou 2, selon lequel ladite composition chimique contient à la fois du Ni et du Cu, en une quantité totale d'au moins 0,5 % en masse, préférentiellement au moins 1 % en masse.

4. Acier laminé à chaud selon l'une quelconque des revendications précédentes, selon lequel l'acier présente un allongement à la rupture d'au moins 10% ou plus préférentiellement d'au moins 12 % longitudinalement et/ou transversalement à la direction de laminage.

5. Acier laminé à chaud selon l'une quelconque des revendications précédentes, selon lequel l'acier présente une résistance au choc d'au moins 50 J/cm^2 lorsqu'une éprouvette Charpy entaillée en V présentant une épaisseur de 5 à 10 mm est mesurée à -40 °C longitudinalement à la direction de laminage.

6. Acier laminé à chaud selon l'une quelconque des revendications précédentes, selon lequel l'acier présentant un rayon de courbure minimum de 4,0 fois l'épaisseur longitudinalement et/ou transversalement à la direction de laminage, plus préférentiellement un rayon de courbure minimum de 3,5 fois l'épaisseur longitudinalement.

7. Acier laminé à chaud selon l'une quelconque des revendications précédentes, selon lequel l'acier présente un allongement à la rupture d'au moins 7 %, préférentiellement d'au moins 8 % ou plus préférentiellement d'au moins 9 % lorsqu'un essai de traction est effectué à travers un cordon de soudure d'un produit en acier laminé à chaud soudé où la soudure est longitudinale par rapport à la direction de laminage, selon lequel ledit acier laminé à chaud est soudé en utilisant un soudage MAG avec renfort, en utilisant un procédé de soudage à chanfrein en V ou en Y, selon lequel une première passe est soudée à partir d'un côté inférieur ou supérieur, préférentiellement à partir d'un côté inférieur, et d'autres passes à partir d'un côté supérieur, en utilisant des consommables de soudage conformément à la norme ENG 89 5 M21, aux qualité(s) commerciale(s) X90 et/ou X96, présentant une résistance à la traction de 890 MPa, préférentiellement de 960 MPa, plus préférentiellement de 1100 MPa et un t8/5 de 5 à 20 secondes, préférentiellement de 6 à 18 secondes, ou de 8 à 12 secondes, selon lequel l'acier soudé présente une rupture située à une distance d'au moins 1 mm de la ligne de fusion.

8. Procédé de fabrication d'acier laminé à chaud selon la revendication 1, selon lequel le procédé comprenant les étapes consistant à :

- chauffer une brame d'acier présentant une composition chimique selon la revendication 1 à une température d'austénitisation de 1000 à 1350 °C,
- laminer à chaud de sorte qu'une température de laminage de finition soit de 760 à 1050 °C,
- tremper à une température de 300 °C ou moins, et procéder à un recuit de revenu à une température de 500 à 650 °C si le temps de revenu est de 1 heure ou plus, ou procéder à un recuit de revenu à une température

de 500 à 750 °C si le temps de revenu est de moins de 1 heure après ladite étape de trempe, selon lequel la microstructure de l'acier laminé à chaud avant l'étape de recuit de revenu contient au moins 90 % en surface de martensite lorsque ladite microstructure est examinée sur ¼ d'épaisseur, et la teneur en ferrite et en perlite avant l'étape de recuit de revenu doit être au total de moins de 10 % en surface.

9. Procédé selon la revendication 8, selon lequel la microstructure de l'acier laminé à chaud avant ladite étape de recuit de revenu contient au moins 95 % en surface de martensite et plus préférentiellement au moins 99 % en surface de martensite lorsque ladite microstructure est examinée sur ¼ d'épaisseur.

10. Procédé selon la revendication 8 ou 9, selon lequel ladite étape de trempe est une étape de trempe directe.

11. Procédé selon l'une quelconque des revendications 8 à 10, selon lequel le procédé comprend l'étape de laminage en bandes dudit acier laminé à chaud et ledit acier laminé à chaud comprend un maximum de 0,005 % en masse de niobium et < 0,15 % en masse de carbone.

12. Procédé selon l'une quelconque des revendications 8 à 10, selon lequel ledit acier laminé à chaud comprend un minimum de 0,005 % en masse de niobium, préférentiellement un minimum de 0,02 % en masse de niobium lorsque l'acier laminé à chaud n'est pas laminé en bandes.

13. Utilisation d'un acier laminé à chaud selon l'une quelconque des revendications 1 à 7 pour le soudage MAG avec renfort, en utilisant un procédé de soudage à chanfrein en V ou en Y, selon lequel une première passe est soudée à partir d'un côté inférieur ou supérieur, préférentiellement à partir d'un côté inférieur, et d'autres passes à partir d'un côté supérieur, en utilisant des consommables de soudage conformément à la norme ENG 89 5 M21, aux qualité(s) commerciale(s) X90 et/ou X96, présentant une résistance à la traction de 1100 MPa, préférentiellement de 960 MPa, plus préférentiellement de 900 MPa, le plus préférentiellement de 890 MPa, et un temps t8/5 de 8 à 12 secondes, préférentiellement de 6 à 18 secondes, plus préférentiellement de 5 à 20 secondes, dans lequel le temps t8/5 est le temps nécessaire à la surface totale de la soudure pour refroidir de 800 °C à 500 °C, selon lequel l'acier soudé présente une rupture située à une distance d'au moins 1 mm de la ligne de fusion.

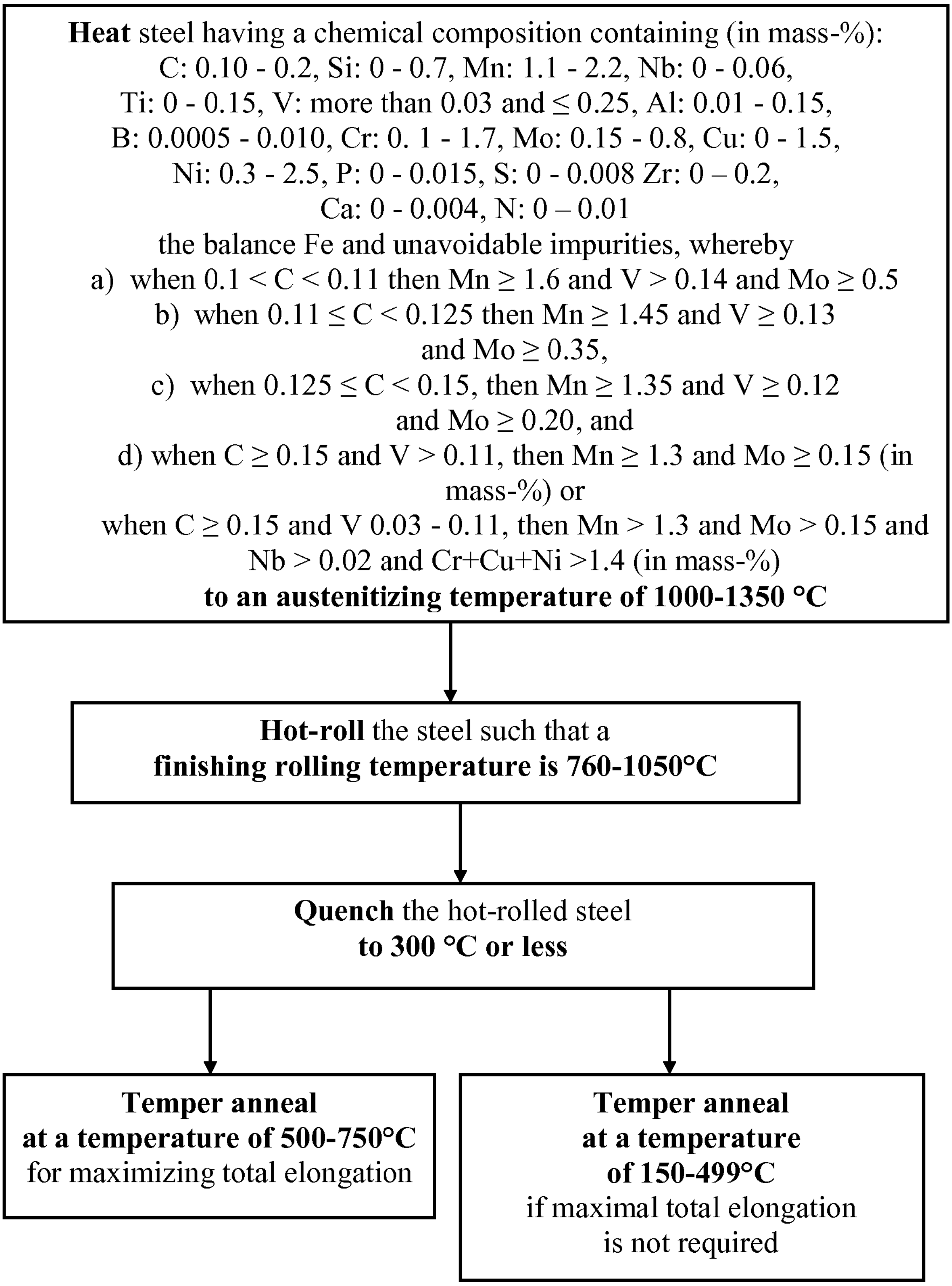
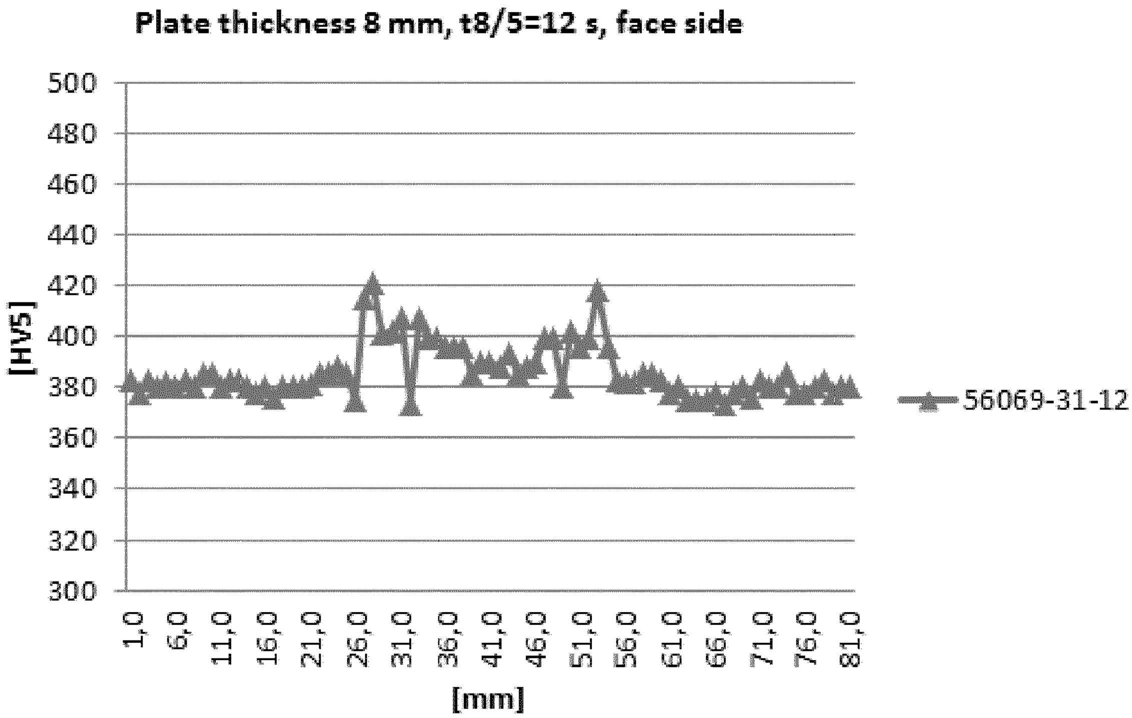

Heat steel having a chemical composition containing (in mass-%):
C: 0.10 - 0.2, Si: 0 - 0.7, Mn: 1.1 - 2.2, Nb: 0 - 0.06,
Ti: 0 - 0.15, V: more than 0.03 and ≤ 0.25, Al: 0.01 - 0.15,
B: 0.0005 - 0.010, Cr: 0. 1 - 1.7, Mo: 0.15 - 0.8, Cu: 0 - 1.5,
Ni: 0.3 - 2.5, P: 0 - 0.015, S: 0 - 0.008 Zr: 0 – 0.2,
Ca: 0 - 0.004, N: 0 – 0.01
the balance Fe and unavoidable impurities, whereby
a) when 0.1 < C < 0.11 then Mn ≥ 1.6 and V > 0.14 and Mo ≥ 0.5
b) when 0.11 ≤ C < 0.125 then Mn ≥ 1.45 and V ≥ 0.13 and Mo ≥ 0.35,
c) when 0.125 ≤ C < 0.15, then Mn ≥ 1.35 and V ≥ 0.12 and Mo ≥ 0.20, and
d) when C ≥ 0.15 and V > 0.11, then Mn ≥ 1.3 and Mo ≥ 0.15 (in mass-%) or
when C ≥ 0.15 and V 0.03 - 0.11, then Mn > 1.3 and Mo > 0.15 and Nb > 0.02 and Cr+Cu+Ni >1.4 (in mass-%)
to an austenitizing temperature of 1000-1350 °C
Hot-roll the steel such that a finishing rolling temperature is 760-1050°C
Quench the hot-rolled steel to 300 °C or less
Temper anneal at a temperature of 500-750°C for maximizing total elongation
Temper anneal at a temperature of 150-499°C if maximal total elongation is not required

Fig. 1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6,0
11,0
16,0
21,0
26,0
31,0
36,0
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71,0
76,0
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[mm]
56069-31-12

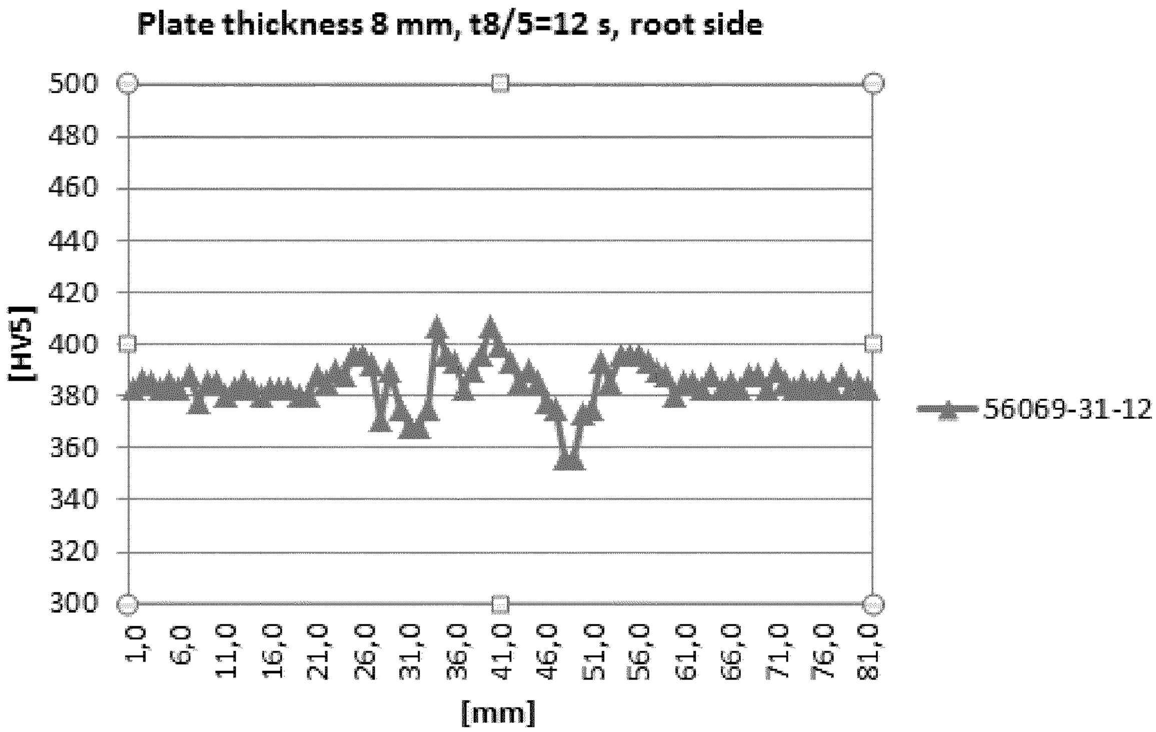
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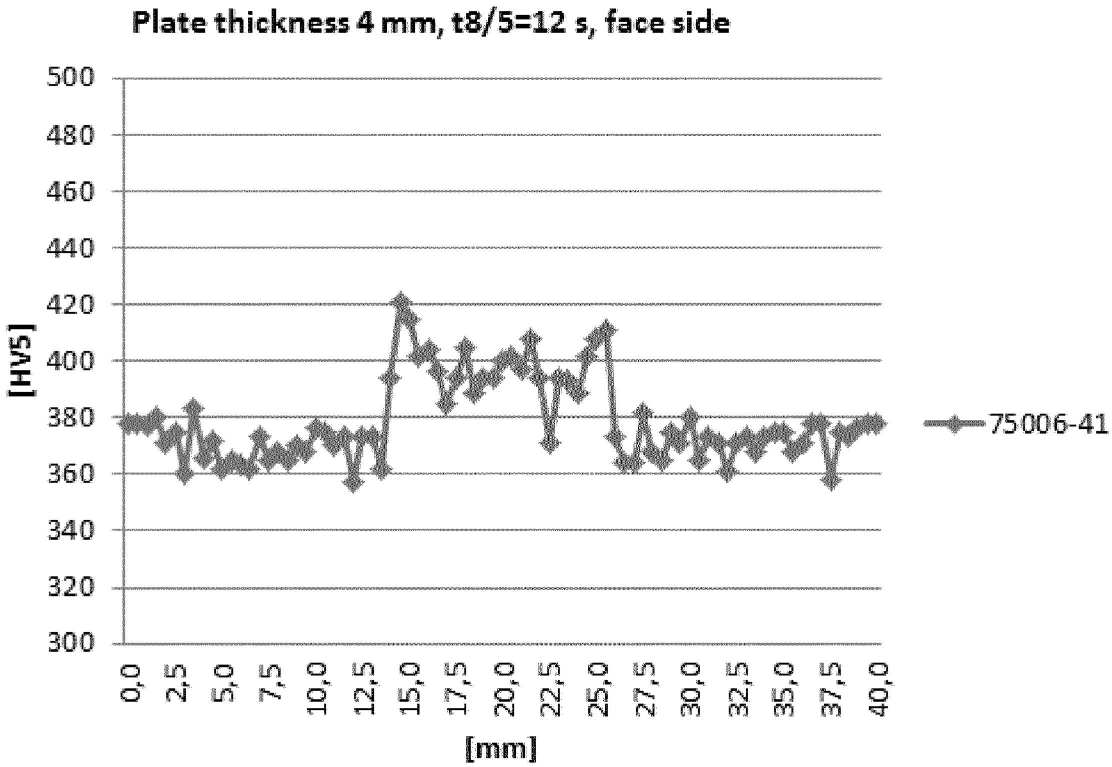
Figure 2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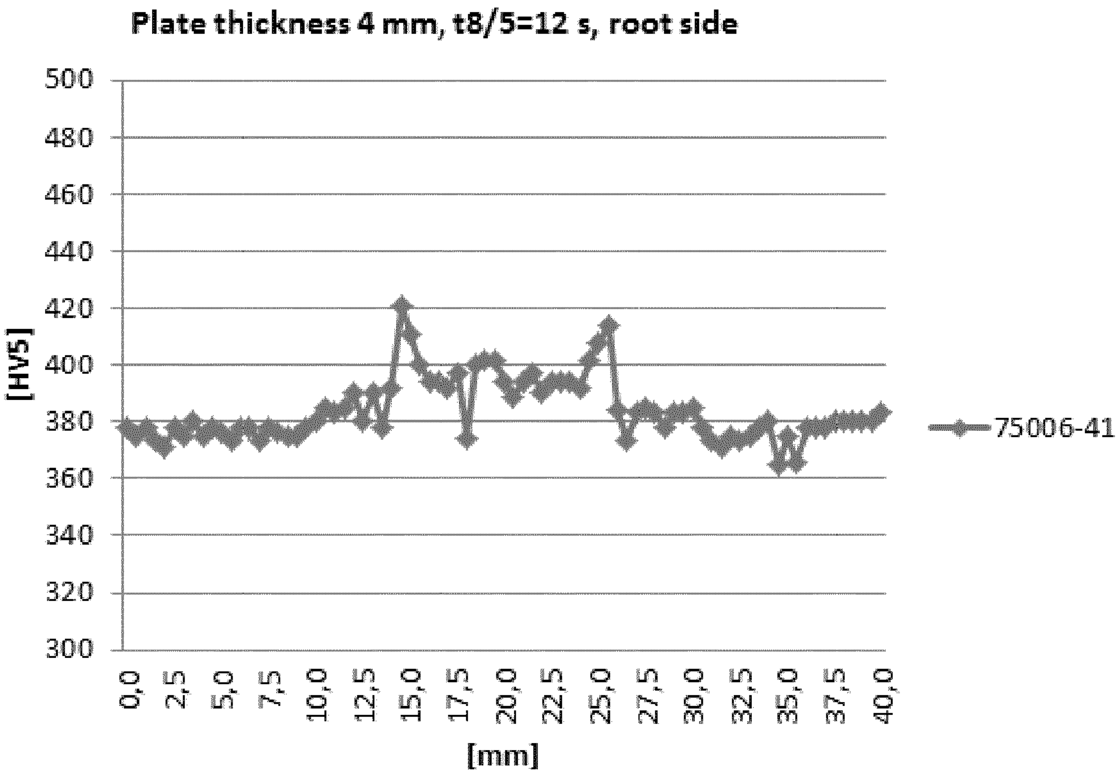
75006-41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32,5
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[mm]
75006-41

Fig. 3

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- EP 2576848 A **[0003]**
- EP 2949775 A1 **[0004]**
- JP 2006206942 A **[0005]**