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(54) **Process for producing an extra-low-carbon or ultra-low-carbon steel slab, strip or sheet, and a slab, strip or sheet produced thereby**

(57) The present invention relates to a process for producing an extra-low-carbon or ultra-low-carbon steel slab, strip or sheet, and to a slab, strip or sheet produced thereby.

EP 2 690 182 A1

Description

[0001] The present invention relates to a process for producing an extra or ultra low carbon steel slab, strip or sheet, and to a slab, strip or sheet produced thereby.

[0002] Canmaking via the DWI (Drawing and Wall Ironing) or DRD (Draw and Redrawing) process takes place at high speed and involves severe plastic strain. Also for deep-drawing or forming of inner and outer panels for automotive applications the demands on formability, particularly high-speed formability, increase. In addition, weldability is also an issue. The steel therefore needs to be of the highest quality and a very low level of non-metallic inclusions is essential to the efficient operation of these processes. However, care must be taken to avoid an excessively large ferrite grain which can give rise to an orange peel effect and a poor surface for lacquering. DWI cans are, for instance, used for beer and soft-drinks, pet foods and human foodware, but also for battery cans. DRD cans are, for instance, used for pet foods and human foodware. Low levels of non-metallic inclusions are also very important for electrical steels and steels for automotive applications, not only for improving formability, but also for improving weldability.

[0003] Steels currently in production rely on the use of small precipitates to prevent the grains from becoming too large. However, the disadvantage is that the formability may be adversely affected by the presence of the precipitates. Also, the presence of precipitates adversely affects the magnetic properties for transformer steels because the precipitates hamper the motion of magnetic domain walls.

[0004] To prevent the formation of the non-metallic inclusions as a result of clogging, it has been proposed that a calcium treatment would prevent clogging. However, it was found that in calcium treated aluminium-killed titanium alloyed ultra low carbon steels calcium aluminate inclusions are frequently encountered. These inclusions are so large that they can be seen on the surface with the naked eye. Apparently this is a problem linked to the ultra low carbon content in combination with the titanium content in the steel, because in low carbon calcium treated steels these large inclusions do not occur.

[0005] It is an object of the invention to provide a process for producing an extra or ultra-low-carbon steel strip with a reduced amount of alumina inclusions or without alumina inclusions.

[0006] It is also an object of the invention to provide an extra or ultra-low-carbon steel which has a shorter annealing time and/or a reduced annealing temperature in a recrystallisation annealing process.

[0007] One or more of these objects are reached with a process for producing an extra or ultra-low-carbon steel strip or sheet, said process comprising:

- producing a vacuum-degassed steel melt in a steelmaking step comprising a ladle treatment
- wherein a final level of the oxygen activity or dissolved oxygen content of the melt at the end of the ladle treatment of the melt is obtained by measuring the actual oxygen content of the melt followed by

A. optionally adding a **first** deoxidant in a suitable form to the melt to reduce the oxygen activity or dissolved oxygen content of the melt to a **first** level of between 3.5 and 40 ppm and optionally measuring the oxygen activity or dissolved oxygen content of the melt;

B. adding a **second** deoxidant that provides more stable oxides than alumina at the steelmaking temperatures in a suitable form to the melt to control or reduce the oxygen activity or dissolved oxygen content of the melt to a **second** level between 3 and 15 ppm;

C. adding alloying elements in a suitable form to create the desired ULC- or ELC-steel type;

D. optionally measuring the oxygen activity or dissolved oxygen content of the melt;

E. and bring the oxygen activity or dissolved oxygen to the final level of at most 15 ppm by adding a third deoxidant that provides more stable oxides than alumina at the steelmaking temperatures in a suitable form to the melt;

- casting the steel thus produced in a continuous casting process to form a slab or strip;
- wherein said process provides a slab, strip or sheet of ultra-low-carbon steel comprising, by weight,

- at most 0.010% carbon,
- at most 0.0150% nitrogen,
- at most 0.20% phosphorus,
- at most 0.300% sulphur, at most 0.002% of acid soluble aluminium
- at most 0.030% silicon
- a total oxygen content of at most 150 ppm
- between 0.05 and 1.2 % manganese
- at most 40 ppm B
- at most 0.100% titanium

- at most 0.100% niobium
- at most 0.200% vanadium
- a total amount of the elements copper, nickel, chromium, tin and molybdenum of at most 0.10%,
- at most 0.1% in total of the first, second and third deoxidant in their metallic form, wherein the first desoxidant is chosen from the group of aluminium (Al), zirconium (Zr), cerium (Ce), tantalum (Ta), calcium (Ca), selenium (Se), barium (Ba) or strontium (Sr) and wherein the second and third desoxidant is chosen from the group of zirconium (Zr), cerium (Ce), tantalum (Ta), calcium (Ca), selenium (Se), barium (Ba) or strontium (Sr);
- balance iron and inevitable impurities.

[0008] With the process according to the invention a steel slab or strip can be produced without alumina containing inclusions, such as calcium aluminates with CaS.

[0009] The essential difference with the conventional process for producing an ultra-low-carbon steel strip or sheet is that the ladle treatment of the melt during the vacuum-degassing step, e.g. in an RH-process or another suitable vacuum-degassing process, does not target a removal of the oxygen by killing it by adding excess aluminium to form alumina particles, but a process wherein the oxygen content of the melt is monitored and controlled, and a dedicated amount of a first deoxidant (such as aluminium) is optionally added if the oxygen content is too high, i.e. not between 3.5 and 40 ppm. If the actual oxygen content is already within these boundaries, then the addition of the first deoxidant is not required, hence the optional character of the addition of the first deoxidant. The first deoxidant is added in a targeted amount based on the measurement of the actual oxygen content of the melt so as to avoid the addition of excess first deoxidant to the melt which would be present in the final steel, in the case of aluminium as a first deoxidant as acid soluble aluminium (i.e. in the form of metallic aluminium, not as alumina). This is the justification for the lower value of 3.5 ppm for the **first** level. Steel melts with an oxygen activity or dissolved oxygen content below 3.5 ppm are considered killed steels. Full killing with the first deoxidant is not desired. It is therefore not a killed steel in the sense of EN10130. The oxides formed during the ladle treatment floats to the slag and the level of first deoxidant in the melt is quickly reduced as a result of the so-called fade. The addition of the precise amount of first deoxidant ensures that substantially all oxide formed during the ladle treatment is removed from the melt prior to solidification during continuous casting, so that the resulting steel contains substantially no oxides of the first deoxidant. The degassing of the molten steel may be made by any conventional methods such as the RH method or the RH-OB method. The oxygen content or activity of the liquid steel may be measured using expendable oxygen sensors or by permanent oxygen sensors. According to the process of the invention the oxygen activity or dissolved oxygen content of the melt must be reduced to the first level of between 3.5 and 40 ppm measured 2 to 5 minutes after the addition of the first deoxidant addition. This range is chosen to obtain a steel with the lowest amount of dissolved first deoxidant to achieve that the liquid steel is not fully killed, but still contains small amounts of oxygen.

[0010] The phrase "at most 0.1% in total of the first, second and third deoxidant in their metallic form" intends to mean that the deoxidant is not present bound to oxygen or as a non-metallic form, but that the atoms are still in the steel as atoms. In case of using aluminium as a deoxidant the usual term for aluminium in the steel in its metallic form is "acid-soluble aluminium", so the term "in their metallic form" is to mean the equivalent term to "acid-soluble aluminium" for other deoxidants such as zirconium etc.

[0011] In an embodiment of the invention at most 0.05%, or preferably at most 0.02%, in total of the first, second and third deoxidant in their metallic form is present in the slab, strip or sheet. The excess of deoxidants is to be minimized to avoid over alloying (costs) and to avoid any deleterious effects of the excess such as the formation of precipitates or attack of the refractory material of the vessels and tundish.

[0012] In an embodiment of the invention aluminium is used as a first deoxidant. Aluminium is cheap and its effects are well understood.

[0013] The oxygen activity can now be controlled between 3 and 15 ppm by the use of a second deoxidant which produces more stable oxides than alumina, such as nongaseous elements such as zirconium (Zr) or cerium (Ce) or tantalum (Ta), or a deoxidant which is gaseous at the steelmaking temperature such as calcium (Ca), selenium (Se), barium (Ba), strontium (Sr). For the purpose of this invention, 1600°C is defined as a typical steelmaking temperature.

[0014] Deoxidants which are gaseous at the steelmaking temperature, such as Ca, Se, Sr and Ba, can be injected into the melt, preferably with a cored wire. Addition directly in the circulating RH(-OB) vessel, e.g. as pellets or gas, is also possible because the flow of the melt in the vessel is such that these gaseous metals (i.e. gaseous at the steelmaking temperature) will have a recovery which, although lower than when injecting cored wire in the melt, is such that the total alloy costs are lower because the alloy can be added in the vessel without a cored wire. For calcium recovery levels of 4 to 12% have been measured.

[0015] In a preferred embodiment Zr is used as second and third deoxidant.

[0016] The zirconium must be added in a suitable form, such as FeZr (80%) to bring down the oxygen activity or dissolved oxygen content of the melt to the second level of between 3 and 15 ppm.

[0017] Alloying elements are subsequently added (in addition to those elements which were added to the melt earlier)

to create the final composition of the melt.

[0018] After stirring or post-circulation for a selected time, e.g. between 2 and 10 minutes, the oxygen activity or dissolved oxygen content of the melt may optionally be measured and the results of the measurements may be used to bring the final level of the oxygen activity or dissolved oxygen to at most 15 ppm by adding a third deoxidant, such as zirconium, in a suitable form and amount to the melt. Again in the case of Zr this may be in the form of FeZr (80%). The alloying elements referred to may be provided in the form of FeTi and/or FeNb for Ti and/or Nb alloyed ULC steels and/or FeP for IF steels requiring more strength. For ordinary ULC steels the alloying elements may e.g. be Mn, P and/or B.

[0019] After the desired final level of the oxygen activity or dissolved oxygen content of the melt is reached, the steel melt is sent to the caster to be cast into a thick or thin slab or into a strip. The final solidified steel slab, strip or sheet of ultra-low-carbon steel comprises at most 0.002% of acid soluble aluminium and at most 0.030% silicon and a total oxygen content of at most 150 ppm. The process according to the invention will not lead to clogging because of alumina, because the alumina residu in the liquid steel is minimised or absent, and the wettability of alumina in steel is adequate to avoid build-ups of alumina in the casting system (tundish nozzle, SES/SEN).

[0020] The carbon content of steel melt is limited to at most 0.0100 wt% because when a higher carbon content is used, the carbon forms carbon monoxide in the manufacturing stage during which the steel is molten, and that CO in turn remains as blow-hole defects in the solidified steel. Moreover, the boiling effect may cause operational problems during casting. It should be noted that the silicon in the solidified steel may be present as silicon oxide and/or as metallic silicon. It should be noted that the carbon content of the solidified steel is at most 0.010% carbon. For an ultra low carbon steel the carbon content is at most 0.006%.

[0021] As a result of this process the grain boundaries are very clean and the recrystallisation temperature of the steel is much lower than conventional ultra-low carbon steels. This phenomenon is attributed to the extremely low levels of silicon and acid soluble aluminium in the final steel strip or sheet and the presence of finely dispersed manganese and/or iron oxide particles, which do not hinder recrystallisation to the extent that small precipitates aluminium nitrides do. Even in Ti stabilised ULC or ELC steels a low amount of aluminium nitrides formed in the hot strip mill can hinder recrystallisation of the strip after cold rolling. As a result of the low recrystallisation temperature of the steel the annealing temperatures can be reduced as well, leading to a more economical process as well as a reduced tendency for grain growth in the product. The reduced annealing temperatures also prevent sticking in batch annealing processes and reduce the risk of rupture in continuous annealing. A further advantage of the very clean grain boundaries is the strongly reduced susceptibility to corrosion on the grain boundaries. This is especially relevant for the application of the steel in the production of battery cases. The coating systems used in the production of batteries may be leaner (e.g. thinner coating layers or fewer coating layers) when using a substrate with a better corrosion resistance. The very clean steels are also beneficial for transformer or other electrical applications. For transformer steels punchability is important, hence the maximum phosphorous content of 0.2%. A suitable maximum value for phosphorous is 0.15%. For other cold-rolled steels, the phosphorous content should preferably be at most 0.025wt%, preferably at most 0.020%.

[0022] During casting very little and preferably no Al is left in the steel, and as a consequence the Si pick-up, which normally occurs according to the following reaction $\text{Al}_{\text{steel}} + \text{SiO}_2 \rightarrow \text{Al}_2\text{O}_3 + \text{Si}_{\text{steel}}$ does not occur due to the low Al-content. The maximum value for silicon is 0.030%, but a suitable maximum for silicon was found to be 0.003%.

[0023] It is preferable that the strip or sheet of ultra-low-carbon steel produced according to the invention comprises at most 0.001% of acid soluble aluminium and/or at most 0.002% silicon. Even more preferable the silicon content is at most 0.001%. Ideally, there is no acid soluble aluminium and no silicon in the solidified steel.

[0024] In an embodiment the **first** deoxidant to be added in a suitable form to the melt to bind oxygen to reduce the oxygen activity or dissolved oxygen content of the melt to a **first** level is aluminium.

[0025] In an embodiment of the invention the **second** deoxidant is zirconium.

[0026] It is possible to conduct the process according to the invention also such that the **first** and **second** and **third** deoxidant is zirconium. In this case the entire process is zirconium based. This means that the likelihood of clogging due to aluminium is eliminated. Although technically feasible and attractive from a clogging point of view, the process is less attractive from a cost point of view as aluminium is, at present, less expensive as a deoxidant than zirconium. It is then a matter of weighing the benefits of the full elimination of alumina clogging against the costs of aluminium versus zirconium as a **first** deoxidant. It is noted that the deoxidation with zirconium can be performed during the vacuum-degassing process step or during the stirring. In any case, the zirconia is allowed to float during the post-circulation after the vacuum-degassing process step or during the stirring step. Usually about 75% or more of the zirconia is removed from the melt that way. Alloying elements are subsequently added as before to create the final composition of the melt. After stirring for a selected time, e.g. between 2 and 10 minutes, the oxygen activity or dissolved oxygen content of the melt may optionally be measured and the results of the measurements may be used to bring the final level of the oxygen activity or dissolved oxygen to at most 15 ppm by adding a **third** deoxidant in a suitable form and amount to the melt followed by casting as before. If deemed necessary there can also be additions of the **third** deoxidant in the tundish, i.e. immediately prior to casting to fine tune the desoxidation. Preferably the second and third deoxidant are the same, and preferably they are zirconium. The final solidified steel slab, strip or sheet of ultra-low-carbon steel comprises no

acid soluble aluminium (unless present as an inevitable impurity as a result of carry-over from earlier melts in the steelmaking equipment) and at most 0.030% silicon and a total oxygen content of at most 150 ppm.

[0027] Preferably the oxygen activity or dissolved oxygen content of the melt at this stage of the process is has been reduced to at most 20 ppm.

[0028] Preferably the final level of the oxygen activity or dissolved oxygen content of the melt must be reduced to at most 3.5 ppm. The steel only contains a small amount of the deoxidant which produces more stable oxides than alumina. Excess desoxidant, such as Zr, may result in a reaction of the desoxidant with the refractory of the ladle wall and casting system so that break-outs may occur (e.g. in ladle, tundish, slide gates, stopper area).

[0029] The advantages of the steels produced by the process according to the invention are manifold. The strong reduction or even absence of clogging due to a reduced amount or complete elimination of alumina formed during the process is evident, leading to fewer or no alumina based inclusions and thereby to fewer or no alumina related steel cleanness or surface issues of the final product.

[0030] The reduction of the oxygen activity or dissolved oxygen content caused by the additions of desoxidant such as zirconium decreases the risk of pin hole defects because the likelihood of gas bubbles forming in the steel is strongly reduced as a result of the lower oxygen activity.

[0031] An unexpected benefit is that the annealing temperature of the cold-rolled material (after first having been hot rolled, cooled, coiled and pickled in a conventional manner usual for ULC or stabilised ULC steels) is much lower than that of conventionally fully aluminium killed ULC or stabilised ULC steels because of the absence of the AlN precipitates that are normally present in the steel. The annealing temperature of the cold-rolled material produced according to the invention is between about 50 to 100°C lower than when recrystallisation annealing conventional material. The annealing time during batch annealing can be reduced by several hours.

[0032] The absence of metallic aluminium in the steel slab or strip prevents the formation of aluminium-nitride precipitates at later stages of the process and therefore provides clean grain boundaries. Moreover, the absence of AlN also prevents many problems associated with the dissolution and precipitation characteristics of AlN in the hot strip process such as inhomogeneities of the microstructure and properties over length and width of the strip as a result of the difference in thermal path of different positions of the hot rolled strip in coiled form. There is no need to dissolve the AlN in the reheating furnace of a hot strip mill so a lower furnace temperature can be used, nor is there a need to use a high coiling temperature to allow the AlN to precipitate in the coil. In the Ti-stabilised IF steels or partially stabilised Ti-IF steels, the TiN-particles are formed in the slab and reheating furnace. These are rather large. The amount of small oxides in the steel creates a stable and predictable nitride precipitation. The low coiling temperature in turn leads to an improved pickling ability. The chemistry of the slab or strip results in the formation of finely dispersed oxides, comprising mainly manganese oxides or manganese oxy-sulphides (the sulphides form during solidification in the slab. Of these inclusions, relatively large size inclusions act as nuclei for the recrystallisation during annealing of cold-rolled steel, while relatively small size inclusions may act to become appropriate barriers with respect to grain coarsening caused after the recrystallisation to thereby control the grain size of the steel.

[0033] According to a second aspect an extra-low-carbon or ultra-low-carbon steel slab, strip or sheet is provided produced by a process comprising:

- producing a vacuum-degassed steel melt in a steelmaking step comprising a ladle treatment
- wherein a final level of the oxygen activity or dissolved oxygen content of the melt at the end of the ladle treatment of the melt is obtained by measuring the actual oxygen content of the melt followed by

A. optionally adding a **first** deoxidant in a suitable form to the melt to bind oxygen to bring down the oxygen activity or dissolved oxygen content of the melt to a **first** level of between 3.5 and 40 ppm and optionally measuring the oxygen activity or dissolved oxygen content of the melt

B. adding a **second** deoxidant that provides more stable oxides than alumina at the steelmaking temperatures in a suitable form to the melt to control or bring down the oxygen activity or dissolved oxygen content of the melt to a **second** level between 3 and 15 ppm;

C. adding alloying elements in a suitable form to create the desired ULC- or ELC-steel type;

D. optionally measuring the oxygen activity or dissolved oxygen content of the melt;

E. and bring the oxygen activity or dissolved oxygen to the **final** level of at most 15 ppm by adding a **third** deoxidant that provides more stable oxides than alumina at the steelmaking temperatures in a suitable form to the melt;

- casting the steel thus produced in a continuous casting process to form a slab or strip;
- wherein the slab, strip or sheet of an extra-low-carbon or ultra-low-carbon steel comprises, by weight,

○ at most 0.010% carbon,

- at most 0.0150% nitrogen,
- at most 0.20% phosphorus,
- at most 0.300% sulphur, at most 0.002% of acid soluble aluminium
- at most 0.030% silicon
- a total oxygen content of at most 150 ppm
- between 0.05 and 1.2% manganese
- at most 40 ppm B
- at most 0.100% titanium
- at most 0.100% niobium
- at most 0.200% vanadium
- a total amount of the elements copper, nickel, chromium, tin and molybdenum of at most 0.10%,
- at most 0.1% in total of the **first**, **second** and/or **third** deoxidant in their metallic form, wherein the **first** desoxidant is chosen from the group of aluminium (Al), zirconium (Zr), cerium (Ce), tantalum (Ta), calcium (Ca), selenium (Se), barium (Ba) or strontium (Sr) and wherein the **second** and **third** desoxidant is chosen from the group of zirconium (Zr), cerium (Ce), tantalum (Ta), calcium (Ca), selenium (Se), barium (Ba) or strontium (Sr); ;
- balance iron and inevitable impurities.

[0034] In an embodiment a process is provided for producing a slab or strip wherein the slab, strip or sheet comprises

- at most 0.006% carbon, and/or
- between 0.05 and 0.35% manganese, and/or
- at most 0.006% nitrogen, and/or
- at most 0.025% phosphorus, and/or
- at most 0.020% sulphur, and/or
- at most 0.05% titanium, at most 0.05% niobium, at most 0.05% zirconium, at most 0.10% vanadium

[0035] In an embodiment the steel slab or strip comprises

- at most 5 ppm B, or if the steel comprises B as an alloying elements the B-level is between 10 and 30 ppm B and/or
- at most 0.004% carbon, preferably at most 0.003%, 0.0028%, 0.0025% or even 0.002% carbon and/or
- at most 0.005% nitrogen, preferably at most 0.004 and/or more preferably between 0.0012 and 0.0030% nitrogen. A suitable upper boundary for nitrogen is 0.0030%.

[0036] Preferably the boron free steel comprises at most 1 ppm B. Preferably the Boron containing steel comprises between 10 and 25 ppm B. The carbon content of at most 0.004% carbon, preferably at most 0.002% is intended to minimise the risk of CO-formation, carbide formation and carbon ageing issues.

[0037] In an embodiment the manganese content is between 0.10 and 0.35%. Suitable maximum values for P and S in the solidified steel are 0.020 and 0.010 respectively.

[0038] Preferably, the sulphur content is at most 0.010%, more preferably at most 0.005%.

[0039] In an embodiment a process is provided wherein the steel slab or strip according to the invention is subjected to

- hot-rolling the slab or strip at a temperature above Ar3 to obtain a hot-rolled strip;
- coiling the hot-rolled strip;

optionally followed by:

- cold-rolling the hot-rolled strip with a cold rolling reduction of between 40 and 95% to obtain an intermediate cold-rolled strip;
- annealing the intermediate cold-rolled strip;
- optionally subjecting the intermediate cold-rolled strip to a second cold rolling down to a final sheet thickness;
- optionally cutting the strip into sheets or blanks;

[0040] The slab may be heated and hot-rolled prior to hot rolling in a known way. Alternatively, the warm slab may be heated or the hot slab may be hot-rolled directly. In order to save energy and, hence, to achieve a greater economy, the preheating of the steel prior to the hot-rolling is made at a relatively low temperature of 1150°C or lower, although the invention does not exclude the use of higher preheating temperatures.

[0041] The optional second cold rolling may be a conventional temper rolling step, preferably at a reduction of between 0.5 to 10%. However, the second cold rolling may also involve a substantially higher cold rolling reduction of preferably

between 5 and 50% to produce a steel with a higher yield strength.

[0042] In an embodiment the intermediate cold-rolled steel strip or sheet is subjected to a recrystallisation treatment by continuously annealing or by batch-annealing. The annealing process conditions are chosen such that a recrystallised microstructure is obtained throughout the strip. One of the characteristic features of the invention is that the coiling temperature is limited neither to high temperature nor to low temperature. Namely, according to the invention, the steel may be coiled up at temperatures between 500 and 700°C. When the coiling temperature is higher than the above mentioned temperature range, the pickling is impeded due to a too large scale thickness. In an embodiment the coiling temperature is between 530 and 700°C, preferably between 550 and 650°C. A suitable minimum coiling temperature is 570°C, and a suitable maximum is 640°C. The lower coiling temperature can be chosen because there is no AlN-precipitation to be controlled by it. As a result the oxide layer on the strip is thinner and easier to remove by pickling.

[0043] In an embodiment the hot-rolled sheet has a thickness of between 2.0 and 3.5 mm, the hot-rolled strip is cold rolled with a reduction ratio of between 85 and 96%, preferably between 85 and 95%, and wherein the second cold rolling reduction is between 0.5 and 10%. Preferably the reduction ratio is between 87 and 93%. For double cold rolled steels the second cold rolling reduction is preferably between 5 and 50%

[0044] In an embodiment the ultra-low-carbon steel strip or sheet according to the invention comprises at most 0.001% titanium and at most 0.001% niobium weight, and at most 0.001% vanadium by weight. It is important that the amount of elements causing deoxidation are minimised. Hence the silicon content of the melt is preferably minimised to 0.030 or even 0.020%.

[0045] The steel may be coated with a metallic and/or polymer coating system.

[0046] According to a third aspect the ultra-low carbon steel sheet according to the invention is used in packaging applications such as cans for packaging foodstuff or beverages or in packaging applications such as batteries or as electrical steels for applications such as electromagnets or as steels for automotive applications.

[0047] In an embodiment the ultra-low carbon steel sheet according to the invention is used as enamelling steel. The presence of the finely dispersed manganese oxide particles and the clean matrix results in an ability to store hydrogen during the enamelling process and avoids surface defects like fish-scale on the enamelled product.

[0048] The invention will now be illustrated by means of non-limitative examples. Continuously cast slabs were produced of the steel grades listed in table 1.

Table 1: composition in 1/1000 wt.% except C, N and B in ppm

ID	C	Mn	P	S	Si	Al	Al _{sol}	N	Cu	Cr	Nb	Ni	V	Mo	Sn	B	Zr	Ti
2AA	15	175	12	8	0	1	<1	18	22	23	0	20	1	3	3	0	5	1
2AC	20	181	11	9	0	3	<1	19	23	20	0	18	0	1	3	15	5	1
2AE	40	500	11	9	0	3	<1	19	23	20	0	18	0	1	3	15	5	1

Claims

1. Process for producing extra-low carbon or ultra-low-carbon steel strip or sheet, said process comprising:

- producing a vacuum-degassed steel melt in a steelmaking step comprising a ladle treatment
- wherein a **final** total oxygen content of the melt at the end of the ladle treatment of the melt is obtained by measuring the actual oxygen content of the melt followed by

A. optionally adding a **first** deoxidant to the melt to bind oxygen to bring down the oxygen activity or dissolved oxygen content of the melt to a **first** level of between 3.5 and 40 ppm and optionally measuring the oxygen activity or dissolved oxygen content of the melt

B. adding a **second** deoxidant that provides more stable oxides than alumina at the steelmaking temperatures in a suitable form to the melt to control or bring down the oxygen activity or dissolved oxygen content of the melt to a **second** level between 3 and 15 ppm;

C. adding alloying elements in a suitable form to create the desired ULC- or ELC-steel type;

D. optionally measuring the oxygen activity or dissolved oxygen content of the melt;

E. and bring the oxygen activity or dissolved oxygen to the **final** level of at most 15 ppm by adding suitable amounts of a **third** deoxidant that provides more stable oxides than alumina at the steelmaking temperatures in a suitable form to the melt;

- casting the steel thus produced in a continuous casting process to form a slab or strip;

- wherein said process provides a slab, strip or sheet of ultra-low-carbon steel comprising, by weight,

- at most 0.010% carbon;
- at most 0.0150% nitrogen;
- at most 0.20% phosphorus;
- at most 0.300% sulphur;
- at most 0.002% of acid soluble aluminium;
- at most 0.030% silicon;
- a total oxygen content of at most 150 ppm;
- between 0.05 and 1.2% manganese;
- at most 40 ppm B;
- at most 0.100% titanium;
- at most 0.100% niobium;
- at most 0.200% vanadium;
- a total amount of the elements copper, nickel, chromium, tin and molybdenum of at most 0.10%;
- at most 0.1% in total of the **first**, **second** and **third** deoxidant in their metallic form, wherein the **first** deoxidant is chosen from the group of aluminium (Al), zirconium (Zr), cerium (Ce), tantalum (Ta), calcium (Ca), selenium (Se), barium (Ba) or strontium (Sr) and wherein the **second** and **third** deoxidant is chosen from the group of zirconium (Zr), cerium (Ce), tantalum (Ta), calcium (Ca), selenium (Se), barium (Ba) or strontium (Sr);
- balance iron and inevitable impurities.

2. Process according to claim 1 wherein the **first** deoxidant is aluminium.

3. Process according to claim 1 wherein the **second** deoxidant is the same as the **first** deoxidant.

4. Process according to claim 1 or 2 wherein the **first**, **second** and/or **third** deoxidant is liquid at steelmaking temperatures, preferably wherein the first and/or second deoxidant is zirconium.

5. Process according to claim 1 wherein the **first**, **second** and/or **third** deoxidant is gaseous at the steelmaking temperatures, preferably wherein the **first**, **second** and/or **third** deoxidant is calcium (Ca), selenium (Se), barium (Ba), strontium (Sr) and/or tantalum (Ta).

6. Process according to any one of claims 1 to 5 wherein the **first** level of oxygen activity or dissolved oxygen content of the melt is at most 20 ppm.

7. Process according to any one of claims 1 to 5 wherein the **final** level of oxygen activity or dissolved oxygen content of the melt is at most 3 ppm.

8. Process according to any one of claims 1 to 5 wherein the vacuum-degassed steel melt in the steelmaking step comprising a ladle treatment comprises, by weight, preferably less than 0.0080 wt.% N.

9. Process according to any one of claims 1 to 5 wherein the vacuum-degassed steel melt in the steelmaking step comprising a ladle treatment comprises, by weight, preferably less than 0.020 wt.% S.

10. Process according to any one of claims 1 and 3 to 9 wherein the **first**, **second** and/or **third** deoxidant provides more stable oxides than alumina at the steelmaking temperatures, preferably wherein the suitable metal is zirconium.

11. Process according to any one of the preceding claims wherein the deoxidants which are gaseous at the steelmaking temperatures are added to the melt by cored wire or by adding it as solid material to the melt in a degasser unit, such as an RH-vessel.

12. Steel slab strip or sheet produced using the process according to the process of any one of claims 1 to 11.



EUROPEAN SEARCH REPORT

Application Number
EP 12 17 7843

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