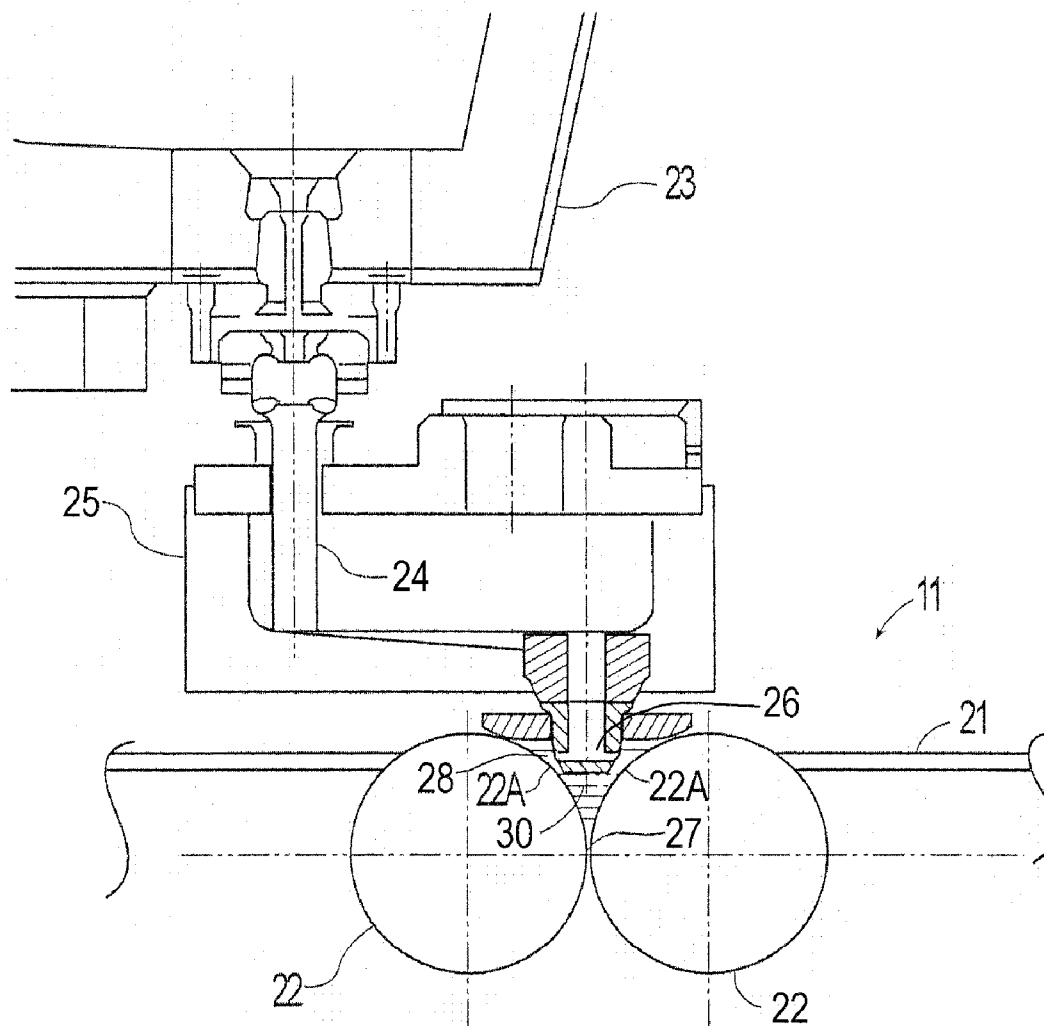




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Mahapatra et al.(10) **Pub. No.: US 2007/0175608 A1**(43) **Pub. Date: Aug. 2, 2007**(54) **THIN CAST STEEL STRIP WITH REDUCED MICROCRACKING****Related U.S. Application Data**(75) Inventors: **Rama Mahapatra**, Brighton-Le-Sands
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(US)(60) Provisional application No. 60/853,322, filed on Jan.
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(52) **U.S. Cl.** **164/480**; 164/459; 164/428(57) **ABSTRACT**(73) Assignee: **NUCOR CORPORATION**, Charlotte,
NC (US)(21) Appl. No.: **11/622,754**(22) Filed: **Jan. 12, 2007**

A thin cast steel strip and method of making thereof with improved resistance to microcracking, where the steel strip is produced by continuous casting and contains between about 0.003% and about 0.008% sulfur by weight and about 0.010% and about 0.065% carbon by weight. The sulfur content may be between about 0.003% and 0.006%.



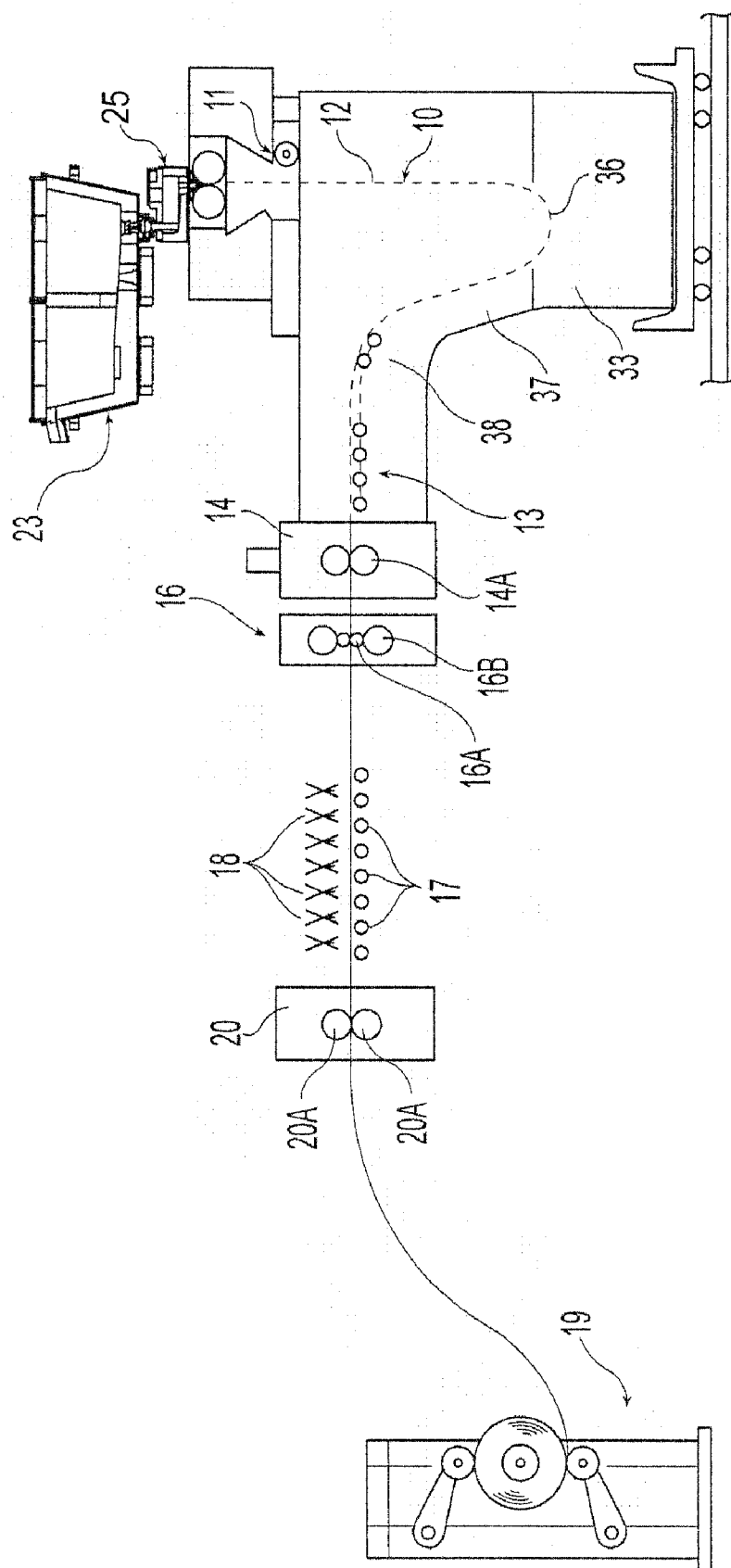


FIG. 1

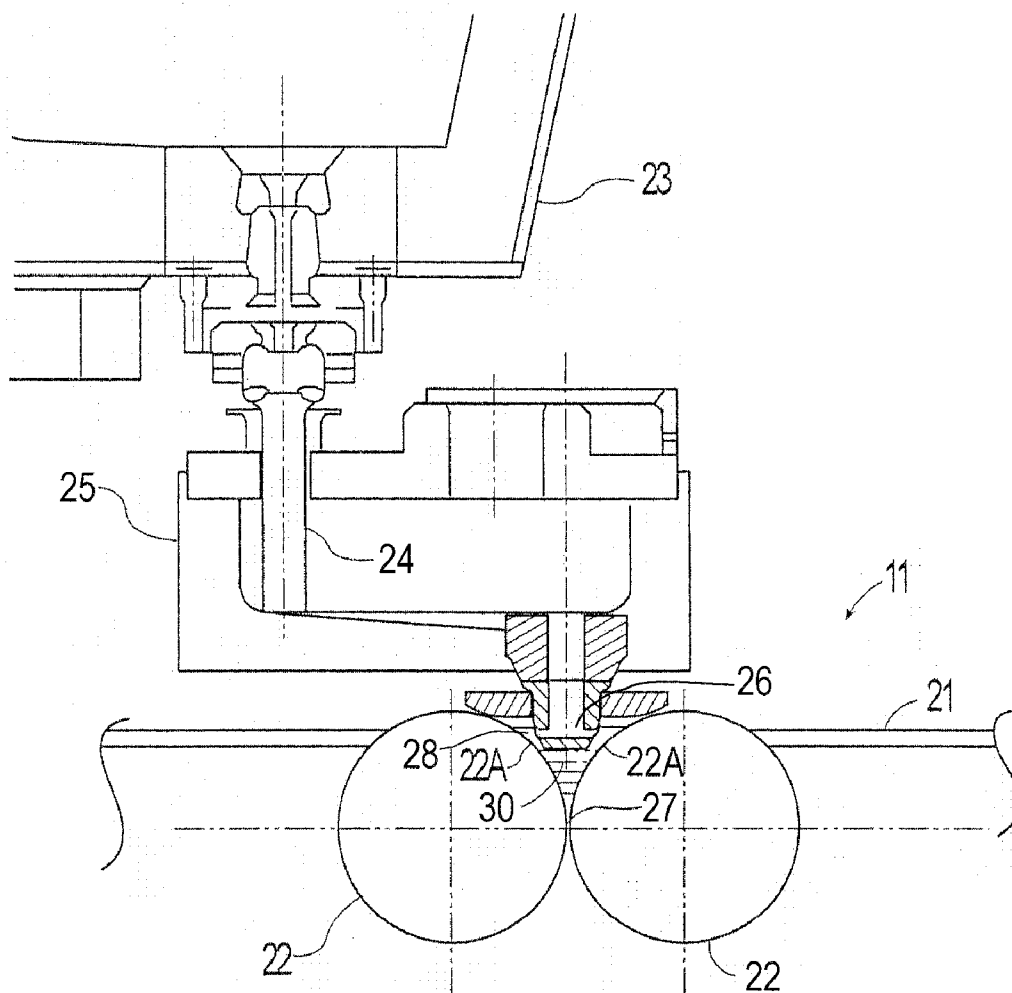


FIG. 2

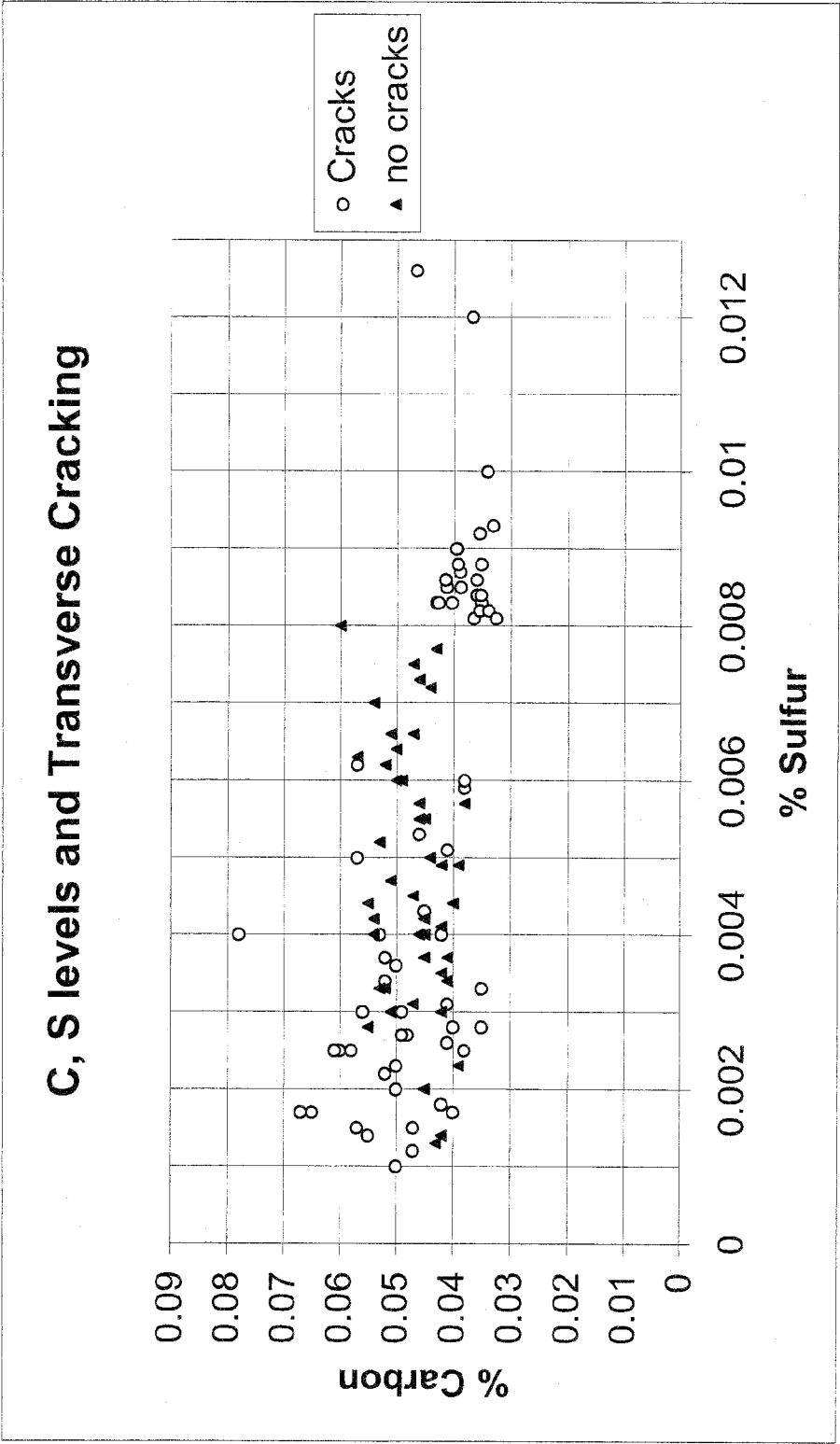


FIG. 3

THIN CAST STEEL STRIP WITH REDUCED MICROCRACKING

RELATED APPLICATION

[0001] This application is filed as the utility application of the provisional application converted from application Ser. No. 11/306,910, filed Jan. 16, 2006, to which priority is claimed.

BACKGROUND AND SUMMARY OF THE INVENTION

[0002] This invention relates generally to steelmaking, and particularly carbon steels formed by continuous casting of thin strip.

[0003] Thin steel strip may be formed by continuous casting in a twin roll caster. In twin roll casting, molten metal is introduced between a pair of counter-rotated laterally positioned casting rolls, which are cooled, so that metal shells solidify on the moving roll surfaces and are brought together at the nip between the rolls to produce a solidified strip product delivered downwardly from the nip. The term "nip" is used herein to refer to the general region at which the rolls are closest together. The molten metal may be poured from a ladle into a smaller vessel from which it flows through a metal delivery nozzle located above the nip to form a casting pool of molten metal supported on the casting surfaces of the rolls and extending along the length of the nip. This casting pool is usually confined between side plates or dams held in sliding engagement with end surfaces of the rolls so as to dam the two ends of the casting pool against outflow.

[0004] When casting thin strip with a twin roll caster, the molten metal in the casting pool will generally be at a temperature of the order of 1500° C. and above. A high heat flux and extensive nucleation on initial solidification of the metal shells on the casting surfaces is needed to form the steel strip. U.S. Pat. No. 5,720,336 describes how the heat flux on initial solidification can be increased by adjusting the steel melt chemistry such that a substantial portion of the metal oxides formed are liquid at the initial solidification temperature. As disclosed in U.S. Pat. Nos. 5,934,359 and 6,059,014 and International Application AU 99/00641, nucleation of the steel on initial solidification can be influenced by the texture of the casting surface. In particular, International Application AU 99/00641 discloses that a random texture of peaks and troughs in the casting surfaces can enhance initial solidification by providing substantial nucleation sites distributed over the casting surfaces.

[0005] Attention has been given in the past to the steel chemistry of the melt, particularly in the ladle metallurgy furnace before the casting of the thin strip. We have given attention in the past, in U.S. application Ser. No. 10/761,953, published as US20040177945A1, to the oxide inclusions and the oxygen levels in the steel metal and their impact on the quality of the steel strip produced. In U.S. application Ser. No. 10/961,300, published as US20050082031A1, we have also regulated hydrogen levels and nitrogen levels in the molten metal to enhance the casting and quality of the steel strip. Finally, in U.S. Pat. No. 6,547,849, we have provided a method of providing silicon/manganese killed molten steel having a sulfur content of less than 0.02% by weight for casting.

[0006] In these prior disclosures, the teachings are generally to have low sulfur levels, say as less than 0.025 or 0.02%. See, e.g., International Application AU 99/00641 and U.S. Pat. No. 6,547,849. There is no suggestion of purposely providing very low levels of sulfur levels to reduce or eliminate microcracking, or for any other purpose.

[0007] Generally, sulfur has been an undesirable impurity in steelmaking, including in continuous casting of thin strip. Steelmakers generally go to great lengths and expense to minimize sulfur content in making steel. Sulfur is primarily present as sulfide inclusions, such as MnS inclusions. Sulfide inclusions may provide sites for voids and/or surface cracking. Sulfur may also decrease ductility and notch impact toughness of the cast steel, especially in the transverse direction. Further, sulfur creates red shortness, or brittleness in red hot steel. Sulfur also reduces weldability.

[0008] Sulfur is generally removed from molten steel by a desulphurization process. Steel for continuous casting may be subjected to a deoxidation and then desulphurization in the ladle metallurgy, prior to casting. One such method involves stirring the molten steel by injecting inert gases, such as argon or nitrogen, while the molten metal is in contact with slag having a high calcium content. See U.S. Pat. No. 6,547,849.

[0009] On the other hand, thin cast strip formed by twin roll casting has been known to have a tendency to form of microcracks in the strip surface. One cause has been the formation of an oxide layer upon the surface of the casting rolls which acts as a thermal barrier causing irregular solidification of the cast strip and formation of microcracks in the strip surface. We have discovered that another cause of microcracks has been the absence of particular levels of sulfur.

[0010] We have found that steel having a sulfur content between about 0.003% and about 0.008% by weight or less is generally desired for casting of thin strip. Just as we have determined that a minimum oxygen content is necessary in steel for casting of thin strip, to improve contact between the casting rolls and the steel and generate high heat flux and rapid initial solidification in formation of thin strip, we have found that a minimum sulfur content is necessary to significantly reduce or eliminate microcracking in continuously strip cast steel.

[0011] The present invention relates to specific sulfur content in steel to substantially reduce or eliminate microcracking in steel. Disclosed is a thin cast steel strip produced by continuous casting by the steps comprising:

[0012] a. assembling a pair of internally cooled casting rolls having a nip between them and with confining closures adjacent the ends of the nip;

[0013] b. introducing molten carbon steel having a sulfur content of between about 0.003% and about 0.008% by weight and a carbon content of between about 0.010% and about 0.065% by weight between the pair of casting rolls to form a casting pool between the casting rolls;

[0014] c. counter rotating the casting rolls to form solidified metal shells on the surfaces of the casting rolls; and

[0015] d. forming from the solidified metal shells thin steel strip downwardly through the nip between the casting rolls.

[0016] The sulfur content of the molten steel in the casting pool may not exceed about 0.006% by weight and may have a sulfur content of no less than about 0.003% by weight. In any event, the thin strip produced has a substantially improved surface quality with less tendency for microcracks.

[0017] The molten steel may be a low carbon steel. Again, the molten steel has a carbon content between about 0.01% and about 0.065%.

[0018] The molten metal in the casting pool may have a total oxygen content of at least 70 ppm and a free oxygen content between 20 and 60 ppm. The steel strip may be formed of a solidified steel containing oxide inclusions distributed corresponding to a total oxygen content in the range 100 ppm to 250 ppm and free oxygen content between 30 and 50 ppm in the molten metal in the casting pool.

[0019] The thin strip may contain fine oxide particles of silicon and iron distributed through the microstructure having an average particle size less than 50 nanometers. The steel strip may also contain oxide particles that increase the resistance to austenite grain coarsening up to at least 1000° C. The steel strip may contain fine oxide particles capable of producing an average austenite grain size of less than 50 microns up to at least 1000° C. for a holding time of at least 20 minutes. The steel strip may be capable of restricting ferrite recrystallization for strain levels up to 10% and temperatures up to 750° C. with hold times up to 20 minutes.

[0020] The thin steel strip may contain, by weight, less than 0.06% aluminum, less than 0.01% titanium, less than 0.01% niobium, and less than 0.02% vanadium.

[0021] The steel strip may be made from a molten melt in the casting pool containing a nitrogen content below about 120 ppm or 100 ppm or 85 ppm, and a free hydrogen content below about 6.9 ppm at atmospheric pressure, and the sum of the partial pressures of hydrogen and nitrogen below 1.15 atmospheres. The molten steel forms thin steel strip having nitrogen and hydrogen levels reflected by the content of the molten steel to provide for the formation of thin steel strip.

[0022] Alternatively, disclosed is a cast thin steel strip, and a method of making thereof, comprises:

[0023] a. introducing molten plain carbon steel on casting surfaces of at least one casting roll with the molten steel having a sulfur content between about 0.003% and about 0.008% by weight and a carbon content between about 0.010% and about 0.065% by weight; and

[0024] b. solidifying the molten steel to form metal shells on the casting rolls and to form thin steel strip there from.

[0025] The steel strip may have a sulfur content between about 0.003% and 0.006%.

[0026] The steel strip may be less than 5 mm or 2.5 mm in thickness. The steel strip may contain solidified oxide inclusions distributed such that surface regions of the strip to a depth of about 2 microns from the surface contain such inclusions a per unit area density of at least 120 inclusions/mm².

[0027] Alternatively, disclosed is a method of casting thin steel strip is provided comprising the steps of:

[0028] a. assembling a pair of cooled casting rolls having a nip there between and confining end closures adjacent to ends of the casting rolls;

[0029] b. introducing molten plain carbon steel between the pair of casting rolls to form a casting pool on casting surfaces of the casting rolls confined by the end closures, with the molten steel having a sulfur content between about 0.003% and about 0.008% by weight and a carbon content between about 0.010% and about 0.065% by weight;

[0030] c. counter-rotating the casting rolls to form solidified metal shells on casting surfaces of the casting rolls; and

[0031] d. forming solidified thin steel strip through the nip between the casting rolls to produce a solidified steel strip delivered downwardly from the nip.

[0032] The steel strip may have a sulfur content between about 0.003% and 0.006%.

[0033] A steel composition is disclosed that comprises:

[0034] a. a carbon content of between about 0.010% and about 0.065% by weight, a silicon content of 2.5% by weight or less, a manganese content of 2.0% by weight or less, and an aluminum content of 1.0% by weight or less; and

[0035] b. a component to reduce the formation of surface microcracks during casting of thin strip, the component comprising a sulfur content between about 0.003% and about 0.008% by weight.

[0036] The steel composition may have a sulfur content between about 0.003% and 0.006%.

[0037] The steel composition may have a silicon content between 0.01% and 2.5% by weight, the manganese content between 0.01% and 2.0% by weight, and the aluminum content is 0.01% by weight or less.

BRIEF DESCRIPTION OF THE DRAWINGS

[0038] FIG. 1 is a diagrammatic side elevation view of an illustrative strip caster,

[0039] FIG. 2 is an enlarged sectional view of a portion of the caster of FIG. 1,

[0040] FIG. 3 shows the relationship between carbon content and sulfur content on microcracking in cast strip steel.

DETAILED DESCRIPTION OF THE DRAWINGS

[0041] Microcracking (generally referred to as "cracking") is a defect that may appear in the surface portions of thin cast strip. Cracking may result from the formation of voids, surface cavities or depressions, or inclusions adjacent the surface of the strip. Cracking may occur during the formation and cooling process.

[0042] We have found that a minimum amount of sulfur is desirable to reduce if not eliminate microcracking in cast thin strip.

[0043] Referring to FIGS. 1 and 2, the thin cast strip, and method of making the same, may be made and used in the continuous strip caster shown. FIGS. 1 and 2 illustrate a twin roll caster denoted generally as 11 which produces a cast steel strip 12 that passes in a transit path 10 across a guide table 13 to a pinch roll stand 14 comprising pinch rolls 14A. Immediately after exiting the pinch roll stand 14, the strip may pass into a hot rolling mill 16 comprising a pair of reduction rolls 16A and backing rolls 16B by in which it is hot rolled to reduce its thickness. The rolled strip passes onto a run-out table 17 on which it may be cooled by convection by contact with water supplied via water jets 18 (or other suitable means) and by radiation. In any event, the rolled strip may then pass through a pinch roll stand 20 comprising a pair or pinch rolls 20A and thence to a coiler 19. Final cooling (if necessary) of the strip takes place on the coiler.

[0044] As shown in FIG. 2, twin roll caster 11 comprises a main machine frame 21 which supports a pair of cooled casting rolls 22 having casting roll surfaces 22A, assembled side-by-side with a nip between them. Molten metal of plain carbon steel may be supplied during a casting operation from a ladle (not shown) to a tundish 23, through a refractory shroud 24 to a distributor 25 and thence through a metal delivery nozzle 26 generally above the nip 27 between the casting rolls 22. The molten metal thus delivered to the nip 27 forms a pool 30 supported on the casting roll surfaces 22A above the nip and this pool is confined at the ends of the rolls by a pair of side closures, dams or plates 28, which may be positioned adjacent the ends of the rolls by a pair of thrusters (not shown) comprising hydraulic cylinder units (or other suitable means) connected to the side plate holders. The upper surface of pool 30 (generally referred to as the "meniscus" level) may rise above the lower end of the delivery nozzle so that the lower end of the delivery nozzle is immersed within this pool.

[0045] Casting rolls 22 are internally water cooled so that shells solidify the moving casting surfaces of the rolls. The shells are then brought together at the nip 27 between the casting rolls sometime with molten metal between the shells, to produce the solidified strip 12 which is delivered downwardly from the nip.

[0046] Frame 21 supports a casting roll carriage which is horizontally movable between an assembly station and a casting station.

[0047] Casting rolls 22 may be counter-rotated through drive shafts (not shown) driven by an electric, hydraulic or pneumatic motor and transmission. Rolls 22 have copper peripheral walls formed with a series of longitudinally extending and circumferentially spaced water cooling passages supplied with cooling water. The rolls may typically be about 500 mm in diameter and up to about 2000 mm long in order to produce strip product of about 2000 mm wide.

[0048] Tundish 23 is of conventional construction. It is formed as a wide dish made of a refractory material such as for example magnesium oxide (MgO). One side of the tundish receives molten metal from the ladle.

[0049] Delivery nozzle 26 is formed as an elongate body made of a refractory material such as for example alumina graphite. Its lower part is tapered so as to converge inwardly and downwardly above the nip between casting rolls 22.

[0050] Nozzle 26 may have a series of horizontally spaced generally vertically extending flow passages to produce a

suitably low velocity discharge of molten metal throughout the width of the rolls and to deliver the molten metal between the rolls onto the roll surfaces where initial solidification occurs. Alternatively, the nozzle may have a single continuous slot outlet to deliver a low velocity curtain of molten metal directly into the nip between the rolls and/or the nozzle may be immersed in the molten metal pool.

[0051] The pool is confined at the ends of the rolls by a pair of side closure plates 28 which are adjacent to and held against stepped ends of the rolls when the roll carriage is at the casting station. Side closure plates 28 are illustratively made of a strong refractory material, for example boron nitride, and have scalloped side edges to match the curvature of the stepped ends of the rolls. The side plates can be mounted in plate holders which are moveable at the casting station by actuation of pair hydraulic cylinder units (or other suitable means) to bring the side plates into engagement with the stepped ends of the casting rolls during a casting operation.

[0052] The twin roll caster may be the kind illustrated and described in some detail in, for example, U.S. Pat. Nos. 5,184,668; 5,277,243; 5,488,988; and/or 5,934,359; U.S. patent application Ser. No. 10/436,336; and International Patent Application PCT/AU93/00593, the disclosures of which are incorporated herein by reference. Reference may be made to those patents for appropriate constructional details by forms no part of the present invention.

[0053] The thin cast steel strip produced by continuous caster may be produced by introducing molten carbon steel having a sulfur content of between about 0.003% and about 0.008% by weight and a carbon content of between about 0.010% and about 0.065% by weight between the pair of casting rolls to form a casting pool supported by the casting rolls above the nip; counter rotating the casting rolls to form solidified metal shells on casting surfaces of the casting rolls; and forming thin steel strip through the nip between the casting rolls from said solidified shells. The molten steel may be a low carbon steel, and the molten steel may have a carbon content between about 0.025% and about 0.060% by weight, or about 0.032% and about 0.045% by weight.

[0054] Referring to FIG. 3, a graph shows the relationship between sulfur content and microcracking for strip cast strip having certain carbon contents made by the twin roll continuous caster illustrated in FIGS. 1 and 2. As shown, microcracks generally occurred when the sulfur levels were below 0.003% weight, and no cracks were generally seen when the sulfur levels were between 0.003% and 0.008% by weight. The sulfur levels may be between 0.003 and 0.008% or between 0.003 and 0.006% by weight to have improved level quality in the cast strip. With higher levels of sulfur above 0.008% cracking was prevalent, and with lower levels for sulfur below 0.003% cracking was prevalent.

[0055] This invention relates to continuously thin cast strip and includes plain carbon steel, low carbon steel, and high austenite grain coarsening temperature steel.

[0056] Plain carbon steel, for example, may include 2.5% or less silicon, 0.5% or less chromium, 2.0% or less manganese, 0.5% or less nickel, 0.25% or less molybdenum, and 1.0% or less aluminum, together with sulfur between 0.003 and 0.008% and phosphorus and other impurities at levels that normally occur in making carbon steel by electric arc furnace.

[0057] Low carbon steel, for example, may include a manganese content in the range 0.01% to 2.0% by weight, and a silicon content in the range 0.01% to 2.5% by weight. The steel may have aluminum content of the order of 0.1% or less by weight, and may, be 0.008% or less by weight.

[0058] Desulphurization may include any commercially known method, which may or may not include stirring and slag formation as described in U.S. Pat. No. 6,547,849. The molten steel may result in a silicon/manganese killed steel.

[0059] While this invention has been described and illustrated with reference to various embodiments, it shall be understood that such description is by way of illustration and not by way of limitation. Accordingly, the scope and content of the present invention are to be defined only by the terms of the appended claims.

I claim:

1. A thin cast steel strip produced by continuous casting by steps comprising:

- a. assembling a pair of internally cooled casting rolls having a nip there between and with confining closures adjacent the ends of the nip;
- b. introducing molten carbon steel having a sulfur content of between about 0.003% and about 0.008% by weight and a carbon content of between about 0.010% and about 0.065% by weight between the pair of casting rolls to form a casting pool supported on the casting surfaces of the casting rolls;
- c. counter rotating the casting rolls to form solidified metal shells on the casting surfaces of the casting rolls; and
- d. forming from said solidified shells thin steel strip downwardly through the nip between the casting rolls.

2. The thin steel strip produced by continuous casting as claimed in claim 1, wherein the molten steel is a low carbon steel.

3. The thin steel strip produced by continuous casting as claimed in claim 1, wherein the molten steel has a carbon content between about 0.025% and about 0.060% by weight.

4. The thin steel strip produced by continuous casting as claimed in claim 1, wherein the molten steel has a carbon content between about 0.032% and about 0.045% by weight.

5. The thin steel strip produced by continuous casting as claimed in claim 1, wherein the sulfur content of the molten steel is between about 0.004% and about 0.006% by weight.

6. The thin steel strip produced by continuous casting as claimed in claim 1, wherein the molten carbon steel in the casting pool has a total oxygen content of at least 70 ppm and a free oxygen content between 20 and 60 ppm.

7. The thin steel strip produced by continuous casting as claimed in claim 1, wherein the steel strip contains, by weight, less than 0.06% aluminum, less than 0.01% titanium, less than 0.01% niobium, and less than 0.02% vanadium.

8. The thin steel strip produced by continuous casting as claimed in claim 1, wherein the steel strip contains fine oxide particles of silicon and iron distributed through the microstructure having an average precipitate size less than 50 nanometers.

9. The thin steel strip produced by continuous casting as claimed in claim 1, wherein the steel strip contains fine oxide particles distributed through the microstructure

capable of producing an average austenite grain size of less than 50 microns up to at least 1000° C. for a holding time of at least 20 minutes.

10. The thin steel strip produced by continuous casting as claimed in claim 1, wherein the steel strip contains fine oxide particles capable of restricting ferrite recrystallization for strain levels up to 10% and temperatures up 750° C. with hold times up to 20 minutes.

11. The thin steel strip produced by continuous casting as claimed in claim 1, wherein the molten metal in the casting pool contains a nitrogen content below about 120 ppm and a free hydrogen content below about 6.9 ppm and the sum of the partial pressures of the hydrogen and nitrogen is less than 1.15 atmospheres.

12. The thin steel strip produced by continuous casting as claimed in claim 1, wherein the molten steel includes nitrogen content below about 100 ppm and free hydrogen content below about 6.9 ppm and the sum of the partial pressures of the hydrogen and nitrogen is less than 1.15 atmospheres.

13. The thin steel strip produced by continuous casting as claimed in claim 1, wherein the molten steel includes free nitrogen content below about 85 ppm and free hydrogen content below about 6.9 ppm and the sum of the partial pressures of the hydrogen and nitrogen is less than 1.15 atmospheres.

14. A method of casting thin steel strip comprising:

- a. introducing molten plain carbon steel on casting surfaces of at least one casting roll with the molten steel having a sulfur content between about 0.003% and about 0.008% by weight and a carbon content between about 0.01% and about 0.065% by weight; and
- b. solidifying the molten steel to form metal shells on the casting rolls and form thin.

15. A thin steel strip produced by:

casting steel strip from molten steel having a sulfur content between about 0.003% and about 0.008% by weight and a carbon content between about 0.010% and about 0.065% by weight.

16. The thin steel strip as recited in claim 15, wherein the steel strip is less than 5 mm in thickness.

17. The thin steel strip as recited in claim 15, wherein the steel strip is less than 2.5 mm in thickness.

18. The thin steel strip as recited in claim 15, wherein the steel strip is formed of a solidified steel containing solidified oxide inclusions distributed in the surface regions of the strip to a depth of 2 microns from the surface contain such inclusions to a per unit area density of at least 120 inclusions/mm².

19. The thin steel strip as recited in claim 15, wherein the steel strip is formed of a solidified steel containing oxide inclusions distributed to reflect a total oxygen content in the range 70 ppm to 250 ppm and free oxygen content between 20 and 60 ppm in the made steel from which the strip is made.

20. A method of casting thin steel strip comprising:

- a. assembling a pair of cooled casting rolls having a nip there between and confining end closures adjacent to ends of the casting rolls;
- b. introducing molten plain carbon steel between the pair of casting rolls to form a casting pool on the casting rolls confined by the end closures, with the molten steel

having a sulfur content between about 0.003% and about 0.008% by weight and a carbon content between about 0.010% and about 0.065% by weight;

- c. counter-rotating the casting rolls to form solidified metal shells on casting surfaces of the casting rolls; and
- d. forming from the solidified metal shells downwardly through the nip between the casting rolls thin steel strip.

21. A steel composition comprising:

- a. a carbon content of between about 0.010% and about 0.065% by weight, a silicon content of 2.5% by weight or less, a manganese content of 2.0% by weight or less,

and an aluminum content of 1.0% by weight or less; and

- b. a component to reduce the formation of surface micro-cracks in the cast thin strip, the component comprising a sulfur content between about 0.003% and about 0.008% by weight.

22. The steel composition as recited in claim 20 wherein the silicon content is between about 0.01% and about 2.5% by weight, the manganese content is between about 0.01% and about 2.0% by weight, and the aluminum content is 0.01% by weight or less.

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