



US 20230287543A1

(19) **United States**

(12) **Patent Application Publication**

Sano et al.

(10) **Pub. No.: US 2023/0287543 A1**

(43) **Pub. Date: Sep. 14, 2023**

(54) **METHOD FOR PRODUCING ULTRA-LOW CARBON STEEL PRODUCT**

Publication Classification

(71) Applicant: **JFE Steel Corporation**, Tokyo (JP)

(51) **Int. Cl.**
C22C 38/00 (2006.01)
C21D 8/02 (2006.01)
C21D 9/46 (2006.01)

(72) Inventors: **Keisuke Sano**, Chiyoda-ku, Tokyo (JP);
Masatoshi Ishiwari, Chiyoda-ku, Tokyo (JP); **Masaru Miyake**, Chiyoda-ku, Tokyo (JP); **Kenji Tsuzumi**, Chiyoda-ku, Tokyo (JP)

(52) **U.S. Cl.**
CPC *C22C 38/004* (2013.01); *C21D 8/0236* (2013.01); *C21D 8/0226* (2013.01); *C21D 9/46* (2013.01)

(73) Assignee: **JFE Steel Corporation**, Tokyo (JP)

(57) **ABSTRACT**

(21) Appl. No.: **18/013,326**

A method for producing an ultra-low carbon steel product having a carbon concentration of 0.005% by mass or less includes, at least, a step of adjusting a carbon concentration of molten iron to obtain molten steel, a step of casting the molten steel into a slab, and a step of hot rolling the slab to obtain a hot-rolled steel sheet, in which the method further includes a width reduction step of performing width reduction on the slab with a reduction amount which is predetermined in accordance with the slab width in a direction orthogonal to the rolling direction of the slab.

(22) PCT Filed: **Jul. 5, 2021**

(86) PCT No.: **PCT/JP2021/025374**

§ 371 (c)(1),
(2) Date: **Dec. 28, 2022**

(30) **Foreign Application Priority Data**

Jul. 8, 2020 (JP) 2020-117921

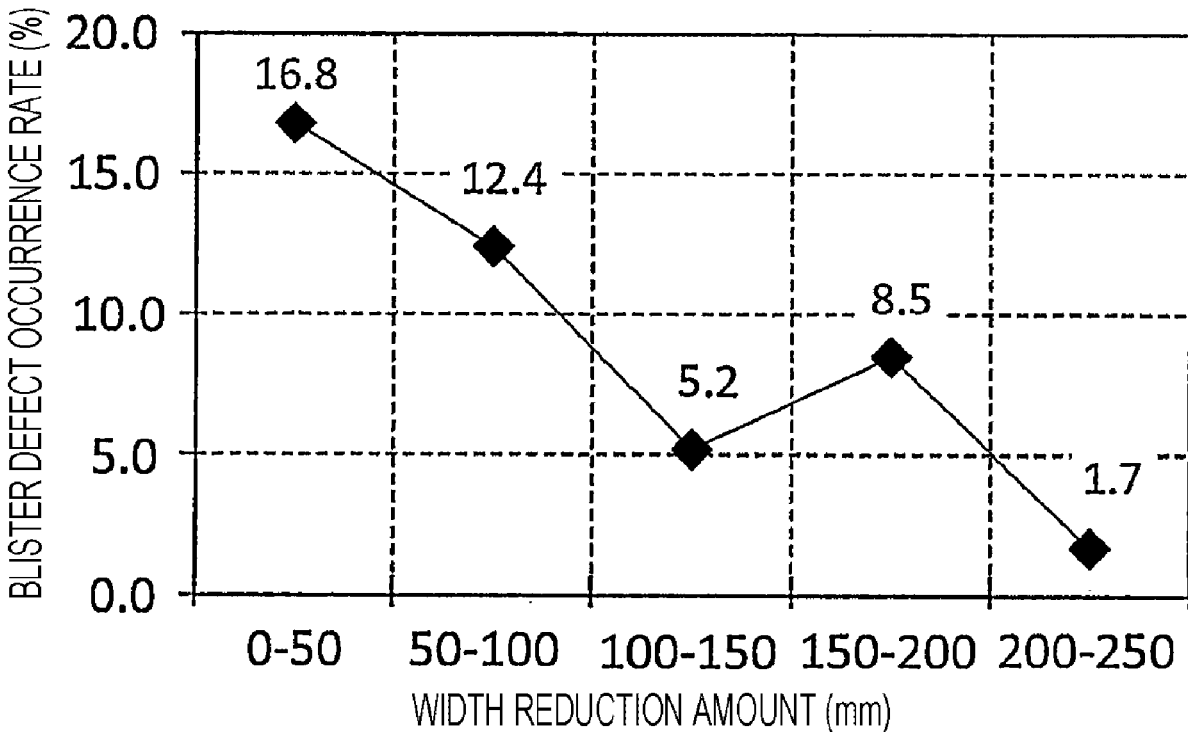


FIG. 1

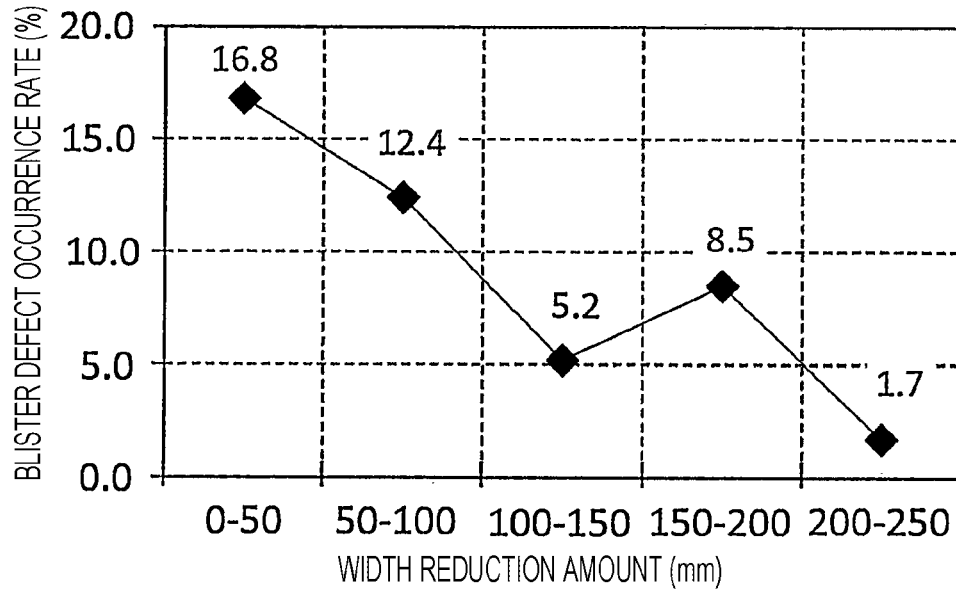
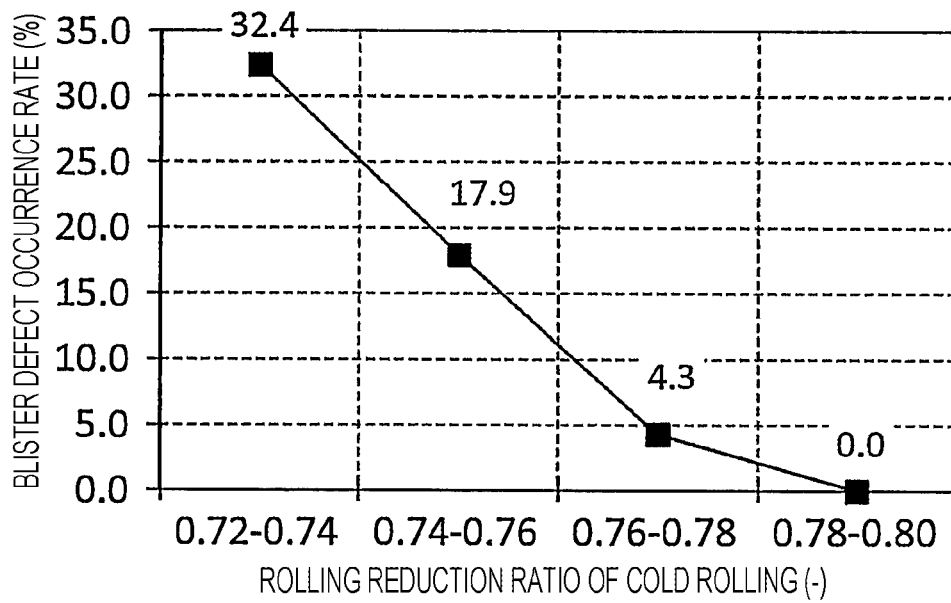


FIG. 2



METHOD FOR PRODUCING ULTRA-LOW CARBON STEEL PRODUCT

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This is the U.S. National Phase application of PCT/JP2021/025374, filed Jul. 5, 2021 which claims priority to Japanese Patent Application No. 2020-117921, filed Jul. 8, 2020, the disclosures of these applications being incorporated herein by reference in their entireties for all purposes.

FIELD OF THE INVENTION

[0002] The present invention relates to a method for producing an ultra-low carbon steel product having a small number of blister defects.

BACKGROUND OF THE INVENTION

[0003] In recent years, regarding cold-rolled steel sheets or surface-treated steel sheets obtained by subjecting cold-rolled steel sheets to coating treatment for automobile use and for can use, requirements for surface quality have become much stricter. In particular, surface defects referred to as “blisters” occurring on the surface of steel sheets are opened by working and cause cracking and deterioration in corrosion resistance. Therefore, occurrence of such defects may in some cases stop shipment of product, resulting in a decrease in yield.

[0004] Blister defects in cold-rolled steel sheets are, as disclosed in Non Patent Literature 1, blister-like surface defects which occur when hydrogen that has entered a steel sheet during pickling after hot rolling is retained in bubbles in the steel sheet, the volume thereof expands with heating during annealing after cold rolling, and the pressure raised by this deforms the surface of the steel sheet that has been softened by heating.

[0005] As a technique for suppressing occurrence of such blisters, Patent Literature 1 discloses a method in which, by a continuous casting machine including a mold having upper magnetic poles and lower magnetic poles and a nozzle having exit ports of molten steel positioned between the magnetic field peak position of the upper magnetic poles and the magnetic field peak position of the lower magnetic poles, a slab is cast while the flow of molten steel being controlled, so that bubbles are suppressed from being captured in a solidified shell, and thus, occurrence of blisters can be suppressed.

PATENT LITERATURE

[0006] PTL 1: Japanese Unexamined Patent Application Publication No. 2011-206846

Non Patent Literature

[0007] NPL 1: Masamichi Kowaka, “Metal Corrosion Damage and Corrosion Protection Technology”, Agune Inc., 1983, p. 207

SUMMARY OF THE INVENTION

[0008] However, the technique disclosed in Patent Literature 1 is a technique in which bubbles which may cause blister defects are suppressed from being captured in the solidified shell mainly at the casting stage. In the casting

step, in order to prevent non-metallic inclusions, such as alumina, from adhering to the inner wall surface of an immersion nozzle, inert gas is introduced into the immersion nozzle. Accordingly, it is difficult to completely prevent bubbles from being captured in a solidified shell. There has been a demand for a method in which, even if bubbles are captured in a solidified shell, occurrence of blister defects can be suppressed in a following hot rolling step and subsequent steps. Aspects of the present invention have been made in consideration of the problem of the existing technique, and it is an object according to aspects of the invention to provide a method for producing an ultra-low carbon steel product in which, even if bubbles are captured in a solidified shell, occurrence of blister defects can be suppressed in a hot rolling step and subsequent steps.

[0009] Aspects of the present invention which solve the problem are as follows:

[0010] (1) A method for producing an ultra-low carbon steel product having a carbon concentration of 0.005% by mass or less, the method including, at least, a refining step of adjusting a carbon concentration of molten iron to obtain molten steel, a casting step of casting the molten steel into a slab, and a hot rolling step of hot rolling the slab to obtain a hot-rolled steel sheet, in which the method further includes a width reduction step of performing width reduction on the slab to be subjected to the hot rolling step with a reduction amount which is predetermined in accordance with the slab width in a direction orthogonal to the rolling direction of the slab.

[0011] (2) A method for producing an ultra-low carbon steel product having a carbon concentration of 0.005% by mass or less, the method including, at least, a refining step of adjusting a carbon concentration of molten iron to obtain molten steel, a casting step of casting the molten steel into a slab, a hot rolling step of hot rolling the slab to obtain a hot-rolled steel sheet, and a cold rolling step of cold rolling the hot-rolled steel sheet to obtain a cold-rolled steel sheet, in which in the cold rolling step, cold rolling is performed at a rolling reduction ratio which is predetermined in accordance with the thickness of the hot-rolled steel sheet.

[0012] (3) The method for producing an ultra-low carbon steel product according to (2), further including a width reduction step of performing width reduction on the slab to be subjected to the hot rolling step with a reduction amount which is predetermined in accordance with the slab width in a direction orthogonal to the rolling direction of the slab.

[0013] By carrying out the method for producing an ultra-low carbon steel product according to aspects of the present invention, it is possible to suppress occurrence of blister defects in an ultra-low carbon steel product produced from an ultra-low carbon steel slab containing bubbles. By suppressing the occurrence of blister defects, improvement in the yield of a production line for ultra-low carbon steel products can be achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. 1 is a graph showing the relationship between the width reduction amount and the blister defect occurrence rate.

[0015] FIG. 2 is a graph showing the relationship between the rolling reduction ratio of cold rolling and the blister defect occurrence rate.

DETAILED DESCRIPTION OF EMBODIMENTS
OF THE INVENTION

[0016] As described above, blister defects occur when hydrogen that has entered a steel sheet during pickling after hot rolling is retained in bubbles and the like in the steel sheet, the volume thereof expands with heating during annealing after cold rolling, and the pressure raised by this deforms the surface of the steel sheet that has been softened by heating. The present inventors have found that by performing width reduction on a slab to be subjected to hot rolling with a reduction amount which is predetermined in accordance with the slab width (size) in a direction orthogonal to the rolling direction of the slab so as to deform bubbles contained in the slab, occurrence of blister defects can be suppressed, and thus aspects of the present invention have been made. Aspects of the present invention will be described below by way of an exemplary embodiment.

[0017] A method for producing an ultra-low carbon steel product according to the embodiment includes, at least, a refining step of adjusting a carbon concentration of molten iron to obtain molten steel, a casting step of casting the molten steel into a slab, a width reduction step of performing width reduction on the slab, and a hot rolling step of hot rolling the slab subjected to width reduction. Furthermore, in some cases, the method may include, after the hot rolling step, a cold rolling step of cold rolling the hot-rolled steel sheet. Molten steel of ultra-low carbon steel is obtained by steelmaking in such a manner that molten steel which has been subjected to a primary refining process in a refining apparatus, such as a converter, in advance is further subjected to a degassing and decarburization process using an RH type degassing apparatus or the like. The step including these processes is an example of the refining step of adjusting a carbon concentration of molten iron to obtain molten steel. In the refining step according to the embodiment, molten steel of ultra-low carbon steel having a carbon concentration of 0.005% by mass or less is obtained.

[0018] The molten steel of ultra-low carbon steel is continuously cast into a slab using a continuous casting machine equipped with a tundish, a mold, foot rolls, guide rolls, pinch rolls, a secondary cooling device, and the like. The step of continuously casting molten steel into a slab using the continuous casting machine is an example of the casting step of casting the molten steel into a slab.

[0019] Subsequently, the slab is subjected to hot rolling to obtain a hot-rolled steel sheet, and by pickling the hot-rolled steel sheet, a hot-rolled steel sheet is produced. Furthermore, the hot-rolled steel sheet may be further subjected to cold rolling, annealing, and other processes to obtain a cold-rolled steel sheet. Moreover, the cold-rolled steel sheet may be subjected to hot-dip galvannealing treatment to obtain a hot-dip galvannealed steel sheet. The step of subjecting the slab to hot rolling including the pickling process to obtain a hot-rolled steel sheet is an example of the step of hot rolling the slab, and the step of subjecting the hot-rolled steel sheet to cold rolling, annealing, and other processes to obtain a cold-rolled steel sheet is an example of the cold rolling step of cold rolling the hot-rolled slab.

[0020] In the casting step, molten steel in a tundish is poured into a mold through an immersion nozzle. The ultra-low carbon steel having a carbon concentration of 0.005% by mass or less contains alumina generated during the degassing and decarburization process using an RH-degassing apparatus. In order to prevent non-metallic inclu-

sions, such as alumina, from adhering and accumulating to the inner wall surface of the immersion nozzle and blocking the immersion nozzle, inert gas, such as Ar gas, is blown into the nozzle through the inner wall surface of the immersion nozzle which is used for pouring molten steel from the tundish into the mold. Bubbles of the inert gas are discharged, together with the molten steel, from molten steel exit ports of the immersion nozzle into the mold.

[0021] When bubbles of the inert gas discharged into the mold are captured in a solidified shell, a slab containing bubbles is cast. When the slab containing bubbles is formed into a hot-rolled steel sheet and when the hot-rolled steel sheet is subjected to pickling, hydrogen is retained in bubbles, the volume thereof expands with heating during annealing after cold rolling, and the pressure raised by this deforms the surface of the steel sheet that has been softened by heating, resulting in the occurrence of blister defects.

[0022] Concerning such blister defects, the method for producing an ultra-low carbon steel product according to the embodiment further includes a width reduction step of performing width reduction on the slab to be subjected to hot rolling with a reduction amount which is predetermined in accordance with the slab width in a direction orthogonal to the rolling direction of the slab. Specifically, using a sizing press, width reduction is performed on the slab to be subjected to hot rolling. In this way, occurrence of blister defects during annealing after cold rolling can be suppressed.

[0023] Next, a mechanism by which occurrence of blister defects is suppressed will be described. When a bubble contained in a slab is considered as a beam, the expansion amount (δ) of the bubble is expressed by formula (1) below, using the beam calculation formula in which both ends of the beam are supported.

$$\delta = WL^2/384EI \quad (1)$$

[0024] In the above formula (1), δ is the expansion amount (m), W is the stress (N), L is the bubble width (m), E is the Young's modulus (MPa), and I is the moment of inertia of area (m⁴).

[0025] By performing width reduction on the slab with a sizing press, the bubble width is narrowed, and L in the formula (1) decreases. When L decreases, the expansion amount (δ) at the center of the beam also decreases. Because of this effect, expansion of bubbles is suppressed, and thus it is considered that occurrence of blister defects is suppressed.

[0026] Next, the relationship between the width reduction amount of the slab and the blister defect occurrence rate will be described. Slabs having a width of 1,100 to 2,100 mm were subjected to width reduction by a sizing press with different reduction amounts, each with a weight of 500 t or more. Each of the slabs subjected to width reduction was hot rolled to obtain a hot-rolled steel sheet (thickness: 2.6 to 4.0 mm), followed by pickling with hydrochloric acid, and then cold rolling was performed at a certain rolling reduction ratio (0.72 to 0.76) to obtain a cold-rolled steel sheet. The resulting cold-rolled steel sheet was subjected to hot-dip galvannealing treatment, and surface defects of the resulting hot-dip galvannealed steel sheet were continuously measured with an on-line surface defect meter. By appearance inspection, SEM analysis, ICP analysis, or the like, it was visually confirmed whether or not the surface defects were blister defects. A value obtained by dividing the mass coils

in which blister defects occurred by the total coil mass was multiplied by 100 to calculate the blister defect occurrence rate. Furthermore, the rolling reduction ratio of cold rolling was calculated in accordance with formula (2) below.

$$\text{Rolling reduction ratio} = \frac{\text{steel sheet thickness at entry of cold rolling} - \text{steel sheet thickness at exit of cold rolling}}{\text{steel sheet thickness at entry of cold rolling}} \quad (2)$$

[0027] The blister defect occurrence rate was confirmed using an ultra-low carbon steel 1 whose standard component concentrations were C concentration: 0.0000 to 0.0020 by mass, Si concentration: 0.00 to 0.03% by mass, Mn concentration: 0.10 to 0.25% by mass, P concentration: 0.010 to 0.020% by mass, S concentration: 0.003 to 0.010% by mass, and N concentration: 0.0000 to 0.0035% by mass, and an ultra-low carbon steel 2 whose standard component concentrations were C concentration: 0.0000 to 0.0015 by mass, Si concentration: 0.00 to 0.03% by mass, Mn concentration: 0.05 to 0.18% by mass, P concentration: 0.000 to 0.010% by mass, S concentration: 0.003 to 0.009% by mass, and N concentration: 0.0000 to 0.0030% by mass.

[0028] FIG. 1 is a graph showing the relationship between the width reduction amount by the sizing press and the blister defect occurrence rate. In FIG. 1, the horizontal axis represents the slab width reduction amount (mm), and the vertical axis represents the blister defect occurrence rate (%). As shown in FIG. 1, although the blister defect occurrence rate slightly increases when the width reduction amount is increased from 100 to 150 mm to 150 to 200 mm, as a whole, the blister defect occurrence rate tends to decrease as the slab width reduction amount is increased. This result shows that by performing width reduction on the slab to be subjected to hot rolling with a reduction amount which is predetermined in accordance with the slab width in a direction orthogonal to the rolling direction of the slab, occurrence of blister defects can be suppressed.

[0029] Here, the proper width reduction amount in accordance with the slab width can be predetermined by grasping the relationship between the width reduction amount and the blister defect occurrence rate shown in FIG. 1 by an experiment or the like. That is, in the example shown in FIG. 1, it is clear that by subjecting a slab with a width of 1,100 to 2,100 mm to width reduction by a sizing press, with a reduction amount of 200 to 250 mm or more, the blister defect occurrence rate can be greatly decreased.

[0030] As described above, by carrying out the method for producing an ultra-low carbon steel product according to the embodiment, it is possible to suppress occurrence of blister defects in an ultra-low carbon steel product produced from an ultra-low carbon steel slab containing bubbles. By suppressing the occurrence of blister defects, improvement in the yield of a production line for ultra-low carbon steel products can be achieved.

[0031] Furthermore, instead of width reduction of the slab, or together with width reduction of the slab, cold rolling may be performed at a rolling reduction ratio which is predetermined in accordance with the thickness of the hot-rolled steel sheet. By performing cold rolling at a predetermined rolling reduction ratio, the dislocation density in the steel microstructure increases, and the size of recrystallized grains decreases during annealing, thereby increasing the strength of the steel sheet. The occurrence of blister defects is suppressed by the increase in the strength.

[0032] Next, the relationship between the rolling reduction ratio of cold rolling and the blister defect occurrence rate will be described. Slabs subjected to width reduction by a sizing press with a certain width reduction amount (0 to 100 mm) were hot rolled to obtain hot-rolled steel sheets (thickness: 2.6 to 4.0 mm), followed by pickling with hydrochloric acid, and then cold rolling was performed at various rolling reduction ratios to obtain cold-rolled steel sheets with different rolling reduction ratios, each with a weight of 200 t or more. Each of the resulting cold-rolled steel sheets was subjected to hot-dip galvannealing treatment, and surface defects of the resulting hot-dip galvannealed steel sheet were continuously measured with an on-line surface defect meter. By appearance inspection, SEM analysis, ICP analysis, or the like, it was confirmed whether or not the surface defects were blister defects, and the blister defect occurrence rate was calculated.

[0033] FIG. 2 is a graph showing the relationship between the rolling reduction ratio of cold rolling and the blister defect occurrence rate. In FIG. 2, the horizontal axis represents cold rolling reduction ratio (-), and the vertical axis represents the blister defect occurrence rate (%). As shown in FIG. 2, the rolling reduction ratio of cold rolling also correlates with the blister defect occurrence rate, and the blister defect occurrence rate tends to decrease as the rolling reduction ratio of cold rolling is increased. This result shows that instead of width reduction of the slab, or together with width reduction of the slab, cold rolling may be performed at a rolling reduction ratio which is predetermined in accordance with the thickness of the hot-rolled steel sheet, and thereby, occurrence of blister defects can be suppressed.

[0034] Furthermore, the proper rolling reduction ratio in accordance with the thickness of the hot-rolled steel sheet can be predetermined by grasping the relationship between the rolling reduction ratio of cold rolling and the blister defect occurrence rate shown in FIG. 2 by an experiment or the like. That is, in the example shown in FIG. 2, it is clear that by performing cold rolling at a rolling reduction ratio of 0.76 or more on a hot-rolled steel sheet with a thickness of 2.6 to 4.0 mm, the blister occurrence rate can be greatly decreased.

[0035] Furthermore, as described above, since the mechanism of suppression of occurrence of blister defects by slab width reduction is different from the mechanism of suppression of occurrence of blister defects by cold rolling, it is clear that by using these techniques together, the occurrence of blister defects can be further suppressed. In the case where slab width reduction and cold rolling are used together, slabs subjected to width reduction with different reduction amounts are prepared, and regarding hot-rolled steel sheets produced from the slabs prepared, the relationship between the cold rolling reduction ratio and the blister defect occurrence rate is grasped in advance by an experiment or the like. In this way, the width reduction amount in accordance with the slab width and the rolling reduction ratio in accordance with the thickness of the hot-rolled steel sheet can be predetermined.

[0036] In the case where the occurrence of blister defects is suppressed by width reduction, an ultra-low carbon steel product produced by the method for producing an ultra-low carbon steel product according to the embodiment is a hot-rolled steel sheet obtained by subjecting an ultra-low carbon steel slab with 0.005% by mass or less to width reduction with a predetermined width reduction amount,

followed by hot rolling and pickling. Furthermore, in the case where the occurrence of blister defects is suppressed by rolling reduction of cold rolling, an ultra-low carbon steel product produced by the method for producing an ultra-low carbon steel product according to the embodiment may be a cold-rolled steel sheet obtained by subjecting an ultra-low carbon steel slab with 0.005% by mass or less to hot rolling, followed by pickling and cold rolling, or may be a hot-dip galvanized steel sheet obtained by subjecting the cold-rolled steel sheet to hot-dip galvannealing treatment.

[0037] Furthermore, the method for producing an ultra-low carbon steel according to the embodiment can be applied not only to the ultra-low carbon steels 1 and 2 described above, but also to an ultra-low carbon steel 3 whose standard component concentrations are C concentration: 0.0000 to 0.0030 by mass, Si concentration: 0.00 to 0.03% by mass, Mn concentration: 0.10 to 0.25% by mass, P concentration: 0.015 to 0.030% by mass, S concentration: 0.005 to 0.012% by mass, and N concentration: 0.0000 to 0.0035% by mass, and an ultra-low carbon steel 4 whose standard component concentrations are C concentration: 0.0000 to 0.0020 by mass, Si concentration: 0.00 to 0.04% by mass, Mn concentration: 0.10 to 0.25% by mass, P concentration: 0.000 to 0.010% by mass, S concentration: 0.004 to 0.012% by mass, and N concentration: 0.0000 to 0.0030% by mass.

1. A method for producing an ultra-low carbon steel product having a carbon concentration of 0.005% by mass or less, the method comprising, at least, a refining step of

adjusting a carbon concentration of molten iron to obtain molten steel, a casting step of casting the molten steel into a slab, and a hot rolling step of hot rolling the slab to obtain a hot-rolled steel sheet,

wherein the method further comprises a width reduction step of performing width reduction on the slab to be subjected to the hot rolling step with a reduction amount which is predetermined in accordance with the slab width in a direction orthogonal to the rolling direction of the slab.

2. A method for producing an ultra-low carbon steel product having a carbon concentration of 0.005% by mass or less, the method comprising, at least, a refining step of adjusting a carbon concentration of molten iron to obtain molten steel, a casting step of casting the molten steel into a slab, a hot rolling step of hot rolling the slab to obtain a hot-rolled steel sheet, and a cold rolling step of cold rolling the hot-rolled steel sheet to obtain a cold-rolled steel sheet,

wherein in the cold rolling step, cold rolling is performed at a rolling reduction ratio which is predetermined in accordance with the thickness of the hot-rolled steel sheet.

3. The method for producing an ultra-low carbon steel product according to claim 2, further comprising a width reduction step of performing width reduction on the slab to be subjected to the hot rolling step with a reduction amount which is predetermined in accordance with the slab width in a direction orthogonal to the rolling direction of the slab.

* * * * *