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(54) FERRITIC STAINLESS STEEL WITH IMPROVED GRAIN BOUNDARY EROSION, AND MANUFACTURING METHOD THEREOF

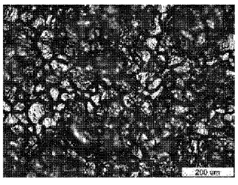
(57) Disclosed is a ferritic stainless steel with reduced grain boundary erosion.

A ferritic stainless steel with reduced grain boundary erosion according to an embodiment includes, in percent by weight (wt%), 0.005 to 0.1% of C, 0.01 to 1.0% of Si, 0.01 to 1.5% of Mn, 13 to 18% of Cr, 0.005 to 0.1% of N, 0.005 to 0.2% of Al, 0.005 to 0.1% of Ni, 0.003% or less of Mo, 0.05% or less of P, 0.005% or less of S, and the remainder being Fe and impurities, and satisfies an Ac1, defined by Formula (1) below, of 900 or more and 990 or less:

$$\text{Formula (1): } Ac1 = 36Cr+90Si+76Mo+760Al+350-(800C+1300N+150Ni+50Mn)$$

(wherein C, N, Si, Mn, Cr, Ni, Al, Mn, and Mo represent a content (wt%) of each element).

【FIG.1A】



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Description

[Technical Field]

[0001] The present disclosure relates to a ferritic stainless steel and a manufacturing method thereof, and more particularly, to a ferritic stainless steel with reduced grain boundary erosion and a manufacturing method thereof.

[Background Art]

[0002] In general, stainless steels are classified according to chemical components or metal structures thereof. According to the metal structures, stainless steels are classified into austenitic (300 series), ferritic (400 series), martensitic, and duplex stainless steels.

[0003] Among them, ferritic stainless steels have higher price competitiveness than austenitic stainless steels because smaller amounts of expensive alloying elements are contained in the ferritic stainless steels. Ferritic stainless steels have been widely used in kitchen utensils, exterior materials of buildings, home appliances, electronic parts, and the like due to excellent surface gloss, drawability, and oxidation resistance.

[0004] Meanwhile, when ferritic stainless billets are reheated and hot-rolled, a dual phase of ferrite and austenite is formed. The austenite is transformed into a martensite phase in the case where the hot-rolled steel material is coiled and cooled, and the martensite has a very high hardness and is not easily deformed.

[0005] Therefore, an annealing process is performed for ferritic stainless steels, as a post process to recrystallize a structure deformed during hot rolling and to decompose an austenite phase generated during hot rolling into a ferrite phase.

[0006] As the annealing process, a continuous annealing method in which annealing is performed after unwinding ferritic stainless steels is generally adopted. However, a batch annealing process in which annealing is performed in an unwound state is performed, instead of the continuous annealing process, for 430 ferritic stainless steels due to easily breaking properties thereof in the case of unwinding.

[0007] During batch annealing, an austenite phase is re-generated at an annealing temperature higher than the austenite transformation temperature and the re-generated austenite phase is re-transformed into martensite during cooling, resulting in deterioration of formability and corrosion resistance.

[0008] Therefore, a batch annealing process is performed via heat treatment at a temperature directly below a phase transformation temperature from the austenite phase into the ferrite phase. In general, because austenite phase transformation occurs at a low temperature of 800 to 850°C, a long time (35 to 50 hours) is taken for the batch annealing process for complete annealing.

[0009] The batch annealing process not only consumes a large amount of energy, but also increases manufacturing costs, thereby deteriorating productivity. In addition, because a long time is required for the batch annealing process, problems such as delay in delivery due to increased manufacturing time may occur.

[0010] Meanwhile, when 430 ferritic stainless steels are acid-pickled by a common acid pickling method after continuous annealing, rather than batch annealing, grain boundary erosion occurs due to a grain boundary Cr depletion region caused by precipitation of a Cr carbide during cooling after hot rolling. In steel materials in which grain boundary erosion occurs, surface defects are caused during subsequent cold working and a problem of deterioration of corrosion resistance may occur.

(Related Art Document)

[0011] (Patent Document 1) Korean Patent Application Laid-Open Publication No. 10-2019-0072279A (Published on June 25, 2019)

[Disclosure]

[Technical Problem]

[0012] To solve problems as described above, provided are a stainless steel having reduced grain boundary erosion, prepared by a method in which a batch annealing process is omitted, and suitable for continuous annealing and a manufacturing method thereof.

[Technical Solution]

[0013] In accordance with an aspect of the present disclosure to achieve the above-described objects, a ferritic stainless

steel with reduced grain boundary erosion includes, in percent by weight (wt%), 0.005 to 0.1% of C, 0.01 to 1.0% of Si, 0.01 to 1.5% of Mn, 13 to 18% of Cr, 0.005 to 0.1% of N, 0.005 to 0.2% of Al, 0.005 to 0.1% of Ni, 0.003% or less of Mo, 0.05% or less of P, 0.005% or less of S, and the remainder being Fe and impurities, and
satisfies an Ac1, defined by Formula (1) below, is 900 or more and 990 or less:

$$\text{Formula (1): } Ac1 = 36Cr+90Si+76Mo+760Al+350-(800C+1300N+150Ni+50Mn)$$

(wherein C, N, Si, Mn, Cr, Ni, Al, Mn, and Mo represent a content (wt%) of each element).

[0014] In addition, according to an embodiment of the present disclosure, the stainless steel may include, in percent by weight (wt%), 0.4 to 1.0% of Mn and 0.1 to 0.15% of Al.

[0015] In accordance with another aspect of the present disclosure, a method of manufacturing a ferritic stainless steel with reduced grain boundary erosion includes: preparing a slab comprising, in percent by weight (wt%), 0.005 to 0.1% of C, 0.01 to 1.0% of Si, 0.01 to 1.5% of Mn, 13 to 18% of Cr, 0.005 to 0.1% of N, 0.005 to 0.2% of Al, 0.005 to 0.1% of Ni, 0.003% or less of Mo, 0.05% or less of P, 0.005% or less of S, and the remainder being Fe and impurities, and satisfying an Ac1, defined by Formula (1) below, of 900 or more and 990 or less; reheating the slab; rough-rolling the reheated slab and finish-rolling the rough-rolled steel material; coiling the hot-rolled steel material; continuous annealing the coiled steel material in a temperature range T(A) defined by Formula (2) below; and acid-pickling the continuous annealed steel material,

$$\text{Formula (1): } Ac1 = 36Cr+90Si+76Mo+760Al+350-(800C+1300N+150Ni+50Mn)$$

(wherein C, N, Si, Mn, Cr, Ni, Al, Mn, and Mo represent a content (wt%) of each element)

$$\text{Formula (2): } 870^\circ C \leq T(A) \leq (Ac1-10)^\circ C$$

[0016] In addition, according to an embodiment of the present disclosure, the slab may further include, in percent by weight (wt%), 0.4 to 1.0% of Mn and 0.1 to 0.15% of Al.

[0017] In addition, according to an embodiment of the present disclosure, the reheating may be performed in a temperature range of 1,000 to 1,200°C.

[0018] In addition, according to an embodiment of the present disclosure, the finish rolling may be performed in a temperature range of 800 to (Ac1-10)°C.

[0019] In addition, according to an embodiment of the present disclosure, the coiling may be performed in a temperature range of 750 to (Ac1-10)°C.

[0020] In addition, according to an embodiment of the present disclosure, the continuous annealing may be performed for 3 to 10 minutes.

[Advantageous Effects]

[0021] According to an embodiment of the present disclosure, continuous annealing is possible by adjusting alloying elements, and thus a ferritic stainless steel with reduced grain boundary erosion and a manufacturing method thereof may be provided.

[Description of Drawings]

[0022]

FIGS. 1A, 1B, and 1C are optical microscopic images of surfaces to observe degrees of grain boundary erosion after acid pickling of hot-rolled and continuous annealed steel sheets.
FIG. 1A is an optical microscopic image showing grain boundary erosion visible in a form being connected along grain boundaries with a great width.
FIG. 1B is an image showing grain boundary erosion visible in a form of lines without being connected along grain

boundaries.

FIG. 1C is an image showing grain boundary erosion visible one some grain boundary traces.

[Best Mode]

[0023] A ferritic stainless steel with reduced grain boundary erosion according to an embodiment of the present disclosure includes, in percent by weight (wt%), 0.005 to 0.1% of C, 0.01 to 1.0% of Si, 0.01 to 1.5% of Mn, 13 to 18% of Cr, 0.005 to 0.1% of N, 0.005 to 0.2% of Al, 0.005 to 0.1% of Ni, 0.003% or less of Mo, 0.05% or less of P, 0.005% or less of S, and the remainder being Fe and impurities, and

satisfies an Ac1, defined by Formula (1) below, of 900 or more and 990 or less:

$$\text{Formula (1): } Ac1 = 36Cr+90Si+76Mo+760Al+350-(800C+1300N+150Ni+50Mn)$$

(wherein C, N, Si, Mn, Cr, Ni, Al, Mn, and Mo represent a content (wt%) of each element).

[Modes of the Invention]

[0024] Hereinafter, embodiments of the present disclosure will be described in detail with reference to the accompanying drawings. The embodiments of the present disclosure may, however, be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the concept of the invention to those skilled in the art.

[0025] Also, the terms used herein are merely used to describe particular embodiments. An expression used in the singular encompasses the expression of the plural, unless otherwise indicated. Throughout the specification, the terms such as "including" or "having" are intended to indicate the existence of features, operations, functions, components, or combinations thereof disclosed in the specification, and are not intended to preclude the possibility that one or more other features, operations, functions, components, or combinations thereof may exist or may be added.

[0026] Meanwhile, unless otherwise defined, all terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. Thus, these terms should not be interpreted in an idealized or overly formal sense unless expressly so defined herein. As used herein, the singular forms are intended to include the plural forms as well, unless the context clearly indicates otherwise.

[0027] The terms "about", "substantially", etc. used throughout the specification means that when a natural manufacturing and a substance allowable error are suggested, such an allowable error corresponds the value or is similar to the value, and such values are intended for the sake of clear understanding of the present disclosure or to prevent an unconscious infringer from illegally using the disclosure of the present disclosure.

[0028] A ferritic stainless steel with reduced grain boundary erosion according to an embodiment of the present disclosure includes, in percent by weight (wt%), 0.005 to 0.1% of C, 0.01 to 1.0% of Si, 0.01 to 1.5% of Mn, 13 to 18% of Cr, 0.005 to 0.1% of N, 0.005 to 0.2% of Al, 0.005 to 0.1% of Ni, 0.003% or less of Mo, 0.05% or less of P, 0.005% or less of S, and the remainder being Fe and impurities.

[0029] Hereinafter, reasons for numerical limitations on the contents of alloying elements will be described.

[0030] <u>A content of carbon (C) is from 0.005 to 0.1%.</u>

[0031] C, as an interstitial solid solution strengthening element, increases strength of a ferritic stainless steel. When the C content is less than 0.005%, an amount of a produced carbide decreases so that sufficient strength cannot be obtained. However, an excess of C may lower a temperature at which a ferrite phase is transformed into an austenite phase and thus an upper limit of continuous annealing temperature is lowered. Therefore, the content of C may be adjusted from 0.005% to 0.1%.

[0032] <u>A content of silicon (Si) is from 0.01 to 1.0%.</u>

[0033] Si, as an alloying element essentially added for deoxidation of a molten steel during a steel making process, improves strength and corrosion resistance and stabilizes a ferrite phase at the same time. Si may be added in an amount of 0.01% or more in the present disclosure. However, an excess of Si may deteriorate ductility and formability, and thus an upper limit thereof is controlled to 1.0%.

[0034] <u>A content of manganese (Mn) is from 0.01 to 1.5%.</u>

[0035] Mn forms uniform scales on a surface layer of a ferritic stainless steel during heat treatment as an element effective on improving corrosion resistance. However, an excess of Mn may generate Mn-based fumes during welding which causes precipitation of an MnS phase, thereby deteriorating elongation. Therefore, a lower limit of the Mn content may preferably be 0.01%, more preferably 0.4%. An upper limit of the Mn content may preferably be 1.5%, more preferably 1.0%.

[0036] A content of chromium (Cr) is from 13 to 18%.

[0037] Cr is an alloying element added to improve corrosion resistance of stainless steels. However, an excess of Cr causes formation of dense oxide scales during hot rolling resulting in sticking defects and increase manufacturing costs. Therefore, the Cr content may preferably be controlled to a range of 13 to 18%.

[0038] A content of nitrogen (N) is from 0.005 to 0.1%.

[0039] Like carbon, nitrogen (N) is an interstitial solid solution strengthening element and improves strength of ferritic stainless steels. However, an excess of N may deteriorate impact toughness and formability of steels and lower transformation temperature at which an austenite phase is transformed to a ferrite phase, thereby lowering an upper limit of the continuous annealing temperature of the present disclosure. Therefore, the N content may preferably be controlled to a range of 0.005 to 0.1%.

[0040] A content of aluminum (Al) is from 0.005 to 0.2%.

[0041] Al, as a ferrite phase-stabilizing element, is a strong deoxidizer that reduces an oxygen content in molten steels. However, an excess of Al may deteriorate ductility at room temperature and increases non-metal inclusions causing sliver defects in cold-rolled strips and deterioration in weldability. Therefore, the Al content may preferably be controlled to a range of 0.005 to 0.2%. A more preferable lower limit of the Al content may be 0.1%, and an even more preferable upper limit thereof may be 0.15%.

[0042] A content of phosphorus (P) is 0.05% or less.

[0043] P, as an impurity inevitably contained in steels, is a major causative element of grain boundary corrosion during acid pickling or deterioration of hot workability, and thus, it is preferable to control the P content as low as possible. Therefore, the P content may preferably be controlled to 0.05% or less.

[0044] A content of sulfur (S) is 0.005% or less.

[0045] S, as an impurity inevitably contained in steels, is a major causative element of deterioration of hot workability as being segregated in grain boundaries, and therefore, it is preferable to control the S content as low as possible. Therefore, the S content may preferably be controlled to 0.005% or less.

[0046] A content of nickel (Ni) is from 0.005 to 0.1%.

[0047] When added in an amount of 0.005%, Ni has effects on improving corrosion resistance. However, an excess of Ni may increase stability of austenite and increase manufacturing costs because Ni is an expensive element. Therefore, the Ni content may be controlled to a range of 0.005 to 0.1%.

[0048] A content of molybdenum (Mo) is 0.003% or less.

[0049] Mo is an element effective on improving corrosion resistance of stainless steels. However, Mo, as an expensive element, may increase manufacturing costs and an excess of Mo may cause deterioration of workability. Therefore, the Mo content may be controlled to 0.003% or less.

[0050] The remaining component of the composition of the present disclosure is iron (Fe). However, the composition may include unintended impurities inevitably incorporated from raw materials or surrounding environments. In the present disclosure, addition of other alloy components in addition to the above-described alloy components is not excluded. The impurities are not specifically mentioned in the present disclosure, as they are known to any person skilled in the art of manufacturing.

[0051] In addition, the ferritic stainless steel according to an embodiment of the present disclosure may satisfy an Ac1, defined by Formula (1) below, of 900 or more and 990 or less.

$$\text{Formula (1): } Ac1 = 36Cr+90Si+76Mo+760Al+350-(800C+1300N+150Ni+50Mn)$$

(wherein C, N, Si, Mn, Cr, Ni, Al, Mn, and Mo represent a content (wt%) of each element)

[0052] The Ac1 refers to an austenite transformation temperature calculated by an alloy composition. In the case of heat treatment at a temperature equal to or higher than the Ac1, a ferrite phase is transformed into an austenite phase. Conventionally, a continuous annealing in which heat treatment is performed for a short time by increasing an austenite transformation temperature by adding an alloy of Ti and Nb has been performed.

[0053] However, Ti may cause problems such as an increase in manufacturing costs of stainless steels and occurrence of sliver defects in cold-rolled products. In addition, Nb may cause defects in an exterior appearance due to inclusions and reduction in toughness and may increase in manufacturing costs as in the case of Ti.

[0054] According to the present disclosure, an annealing temperature at which recrystallization sufficiently occurs during continuous annealing may be obtained by adjusting the Ac1 temperature to 900 or more by controlling contents of austenite-forming elements such as C and N. Also, according to the present disclosure, strength may be increased by forming a carbide and a nitride by adjusting the Ac1 to 990 or less.

[0055] The ferritic stainless steel according to an embodiment of the present disclosure is manufactured according to a method as described below.

[0056] A slab including, in percent by weight (wt%), 0.005 to 0.1% of C, 0.01 to 1.0% of Si, 0.01 to 1.5% of Mn, 13 to 18% of Cr, 0.005 to 0.1% of N, 0.005 to 0.2% of Al, 0.005 to 0.1% of Ni, 0.003% or less of Mo, 0.05% or less of P, 0.005% or less of S, and the remainder being Fe and impurities, and satisfying an Ac1, defined by Formula (1) below, of 900 or more and 990 or less is prepared. The slab is reheated. The reheated slab is rough-rolled and finish-rolled. The hot-rolled stainless steel is coiled. The coiled hot-rolled stainless steel is continuously annealed in a temperature range T(A) defined by Formula (2) below. The continuous annealed steel material is acid-pickled.

$$\text{Formula (1): } Ac1 = 36Cr+90Si+76Mo+760Al+350-(800C+1300N+150Ni+50Mn)$$

(wherein C, N, Si, Mn, Cr, Ni, Al, Mn, and Mo represent a content (wt%) of each element)

$$\text{Formula (2): } 870°C \leq T(A) \leq (Ac1-10)°C$$

[0057] Reasons for numerical limitations on the contents of alloying elements are as described above.

[0058] As an annealing process of a stainless steel-manufacturing process, continuous annealing and batch annealing are used. In general, austenitic stainless steels are annealed by continuous annealing and ferritic and martensitic stainless steels are annealed by batch annealing, according to properties of stainless-steel materials of steel types.

[0059] Upon comparison of annealing processes of hot-rolled coils between stainless steel types, continuous annealing is performed by heat treatment at a high temperature (about 900 to 1150°C) under atmospheric conditions for a short time (about 3 minutes). Unlike this process, batch annealing is performed by heat treatment at a low temperature (about 750 to 850°C) in an ambient gas (hydrogen or mixed gas of nitrogen and hydrogen) for a long time (about 50 hours). In addition, because the batch annealing is performed in a coiled state, a difference in properties of a material may occur between areas due to deviation of annealing temperature at different areas of a hot-rolled coil.

[0060] Meanwhile, ferritic stainless steels are annealed to re-incorporate an austenite phase (martensite phase during cooling) formed after rolling into a ferrite phase and to remove stress generated during hot rolling to facilitate cold rolling.

[0061] When an annealing temperature increases above the austenite transformation temperature while a ferritic stainless steel is annealed, the austenite phase is re-generated during the annealing. The re-generated austenite phase is re-transformed into martensite during cooling, resulting in deterioration of formability and corrosion resistance of steel materials. Therefore, ferrite stainless steels are produced by applying a batch annealing process that proceeds at a low temperature.

[0062] As described above, batch annealing provides lower productivity and lower energy efficiency than continuous annealing. Also, a steel material produced by batch annealing has inferior quality than a steel material produced by continuous annealing due to different annealing temperatures in different areas. Therefore, there is a need to improve a batch annealing process in a process of manufacturing ferritic stainless steels.

[0063] According to an embodiment of the present disclosure, a method of manufacturing a ferritic stainless steel in which continuous annealing is possible for a hot-rolled steel sheet may be provided. In this regard, the continuous annealing is performed in the temperature range T(A) of 870 to (Ac1-10)°C.

[0064] In the case where an annealing temperature is lower than 870°C, recrystallization does not sufficiently occur. At an annealing temperature of Ac1 or higher, an austenite phase is formed. Therefore, there is a need to control the continuous annealing temperature to a range of 870 to (Ac1-10)°C.

[0065] In addition, according to an embodiment of the present disclosure, the reheating may be performed in a temperature range of 1000 to 1200°C.

[0066] When a reheating temperature is low, a rolling load of hot rolling increases and flaws may be generated in billets during hot rolling. In addition, at a low reheating temperature, coarse precipitates generated during casting the slab cannot be re-decomposed. Therefore, in the present disclosure, a lower limit of the reheating temperature is adjusted to 1000°C.

[0067] When the reheating temperature is high, billets may be softened so that a shape changes and coarsening of internal crystal grains cannot be prevented. Therefore, in the present disclosure, an upper limit of the reheating temperature is adjusted to 1200°C.

[0068] In addition, according to an embodiment of the present disclosure, the finish rolling may be performed at a temperature of 800 to (Ac1-10)°C.

[0069] When a finish rolling temperature is below 800°C, flaws may be generated in steel materials and non-uniform structure is formed resulting in deterioration of toughness and strength. At a finish rolling temperature above (Ac1-10)°C, austenite crystal grains are coarsened, and ferrite grain refinement is not sufficiently performed after transformation.

[0070] In addition, according to an embodiment of the present disclosure, the coiling is performed at a temperature of 750 to (Ac1-10)°C,

[0071] A preferable coiling temperature is 750°C or higher for plate shape and surface quality. A coiling temperature above (Ac1-10)°C may correspond to an austenite phase region, a martensite phase may be generated during cooling.

[0072] In addition, according to an embodiment of the present disclosure, the continuous annealing may be performed for 3 to 10 minutes.

[0073] When an annealing time is too short, recrystallization is not sufficiently performed. When the annealing time is too long, grain size increases resulting in deterioration of mechanical properties. In consideration thereof, the annealing time may be controlled to a range of 3 to 10 minutes.

[0074] Meanwhile, surface gloss is an important property of stainless steels, and various manufacturing methods are used to improve the surface gloss. Particularly, because annealing acid pickling is not performed after cold rolling in the case of high-gloss products, a surface before cold rolling remains even after the cold rolling. Therefore, it is important to control the shape of the surface before cold rolling.

[0075] For example, grain boundary erosion, scale residues, or the like, which are caused by excessive acid pickling to remove scales of hot-rolled, annealed stainless steel sheets, form a very rough surface after the hot rolling and acid pickling, and thus surface quality is still inferior even after cold rolling.

[0076] In a shape of grain boundary erosion occurring on the surface of a stainless steel, grain boundaries are folded during cold rolling and may cause surface defects called gold dust defects in final products.

[0077] According to an embodiment of the present disclosure, the ferritic stainless steel manufactured under control conditions of the present disclosure does not have surface grain boundary erosion after acid pickling because continuous annealing temperature is controlled in relation to the austenite phase transformation temperature (Ac1).

[0078] Hereinafter, the present disclosure will be described in more detail through examples. However, it is necessary to note that the following examples are only intended to illustrate the present disclosure in more detail and are not intended to limit the scope of the present disclosure. This is because the scope of the present disclosure is determined by matters described in the claims and able to be reasonably inferred therefrom.

Examples

[0079] Slabs having compositions of alloying elements shown in Table 1 below were prepared by continuous casting and reheated in a temperature range of 1,000 to 1,200°C. The reheated slabs were rough-rolled and finish-rolled using a finish rolling mill at a finish rolling temperature of 800°C, and then coiled at 750°C.

[Table 1]

Category	Alloying elements (wt%)							Ac1	Remarks
	C	Si	Mn	Cr	Ni	Al	N		
Steel A	0.06	0.20	0.80	16.29	0.1	0.08	0.023	880	Comparative Steel
Steel B	0.04	0.20	0.50	16.25	0.1	0.10	0.013	940	Inventive Steel
Steel C	0.03	0.32	0.40	16.20	0.1	0.12	0.010	981	Inventive Steel

[0080] The coiled steel materials were continuous annealed for 10 minutes under the annealing temperature conditions shown in Table 2 below. Subsequently, the hot-rolled and continuously annealed steel sheets were descaled with a short blaster, primarily acid-pickled in a sulfuric acid solution, and then acid-pickled in a mixed acid solution (nitric acid + hydrofluoric acid).

[0081] Table 2 below shows degrees of grain boundary erosion with respect to changes in the continuous annealing temperature after acid pickling.

[0082] The grain boundary erosion was graded into a case in which grain boundary erosion occurred with a great width in a form of being connected along grain boundaries (severe grain boundary erosion) as shown in FIG. 1A, a case in which grain boundary erosion occurred in a form of lines without being connected along the grain boundaries (moderate grain boundary erosion) as shown in FIG. 1B, and a case in which lines were visible on some grain boundary traces (weak grain boundary erosion).

[0083] The severe grain boundary erosion was marked by 'O', the moderate grain boundary erosion was marked by '-', and weak grain boundary erosion was marked by 'X'.

[Table 2]

Category	Steel type	Continuous annealing		Degree of grain boundary erosion
		Annealing temperature (°C)	Ac1-10	
Example 1	Steel B	870	930	X
Example 2	Steel B	900	930	X
Example 3	Steel B	930	930	X
Example 4	Steel C	870	971	X
Example 5	Steel C	900	971	X
Example 6	Steel C	930	971	X
Example 7	Steel C	960	971	X
Comparative Example 1	Steel A	810	870	-
Comparative Example 2	Steel A	840	870	-
Comparative Example 3	Steel A	870	870	X
Comparative Example 4	Steel A	900	870	O
Comparative Example 5	Steel A	930	870	O
Comparative Example 6	Steel A	960	870	O
Comparative Example 7	Steel A	990	870	O
Comparative Example 8	Steel B	810	930	-
Comparative Example 9	Steel B	840	930	-
Comparative Example 10	Steel B	960	930	O
Comparative Example 11	Steel B	990	930	O
Comparative Example 12	Steel C	810	971	-
Comparative Example 13	Steel C	840	971	-
Comparative Example 14	Steel C	990	971	-

[0084] Referring to Table 2, the Ac1-10 value of Inventive Steel B was 930 and the Ac1-10 value of Inventive Steel C was 971. In Examples 1 to 3, Inventive Steel B was continuous annealed in a temperature range of 870 to 930°C. In Examples 4 to 7, Inventive Steel C was continuous annealed in a temperature range of 870 to 971°C. Because Examples 1 to 7 satisfied the alloy compositions, Ac1 values, and continuous annealing temperatures suggested in the present disclosure, weak grain boundary erosion occurred.

[0085] On the contrary, in Comparative Examples 1 and 2, the continuous annealing was performed at 810°C and 840°C, respectively, which are below 870°C, and thus moderate grain boundary erosion occurred.

[0086] Although weak grain boundary erosion occurred in Comparative Example 3, the austenite transformation temperature was low since the Ac1 value was 880 which was below 900. Therefore, a temperature range of Comparative Example 3 is limited during the process and recrystallization is difficult to be sufficiently performed.

[0087] Because the continuous annealing was performed at a temperature above the Ac1-10 in Comparative Examples 4 to 7, severe grain boundary erosion occurred.

[0088] Because Inventive Steel B was continuous annealed at a temperature below 870°C in Comparative Examples 8 and 9, moderate grain boundary erosion occurred.

[0089] In Comparative Examples 10 and 11, Inventive Steel B was continuous annealed at 960°C and 990°C, respectively. Because the continuous annealing temperature of Comparative Examples 10 and 11 exceeded the Ac1-10 value of 930, severe grain boundary erosion occurred.

[0090] Because Inventive Steel B was continuous annealed at temperature below 870°C in Comparative Examples 12 and 13, moderate grain boundary erosion occurred.

[0091] In Comparative Example 14, Inventive Steel C was continuous annealed at 990°C. Because the continuous annealing temperature of Comparative Example 14 exceeded the Ac1-10 value of 971, moderate grain boundary erosion occurred.

[0092] According to the embodiments, when the continuous annealing temperature was below 870°C, moderate grain boundary erosion occurred, and weaker grain boundary erosion occurred at a higher continuous annealing temperature. However, when the continuous annealing temperature exceeded the (Ac1-10)°C, severe grain boundary erosion occurred.

[0093] While the present disclosure has been particularly described with reference to exemplary embodiments, it should be understood by those of skilled in the art that various changes in form and details may be made without departing from the spirit and scope of the present disclosure.

[Industrial Applicability]

[0094] The ferritic stainless steel according to the present disclosure has reduced grain boundary erosion by applying continuous annealing, and accordingly batch annealing may be omitted. Therefore, manufacturing costs are reduced, and the industrial applicability of the present disclosure is considered high.

Claims

1. A ferritic stainless steel with reduced grain boundary erosion comprising, in percent by weight (wt%), 0.005 to 0.1% of C, 0.01 to 1.0% of Si, 0.01 to 1.5% of Mn, 13 to 18% of Cr, 0.005 to 0.1% ofN, 0.005 to 0.2% of Al, 0.005 to 0.1% ofNi, 0.003% or less of Mo, 0.05% or less of P, 0.005% or less of S, and the remainder being Fe and impurities,

   wherein an Ac1, defined by Formula (1) below, is 900 or more and 990 or less:

   $$\text{Formula (1): } Ac1 = 36Cr+90Si+76Mo+760Al+350-(800C+1300N+150Ni+50Mn)$$

   (wherein C, N, Si, Mn, Cr, Ni, Al, Mn, and Mo represent a content (wt%) of each element).

2. The ferritic stainless steel according to claim 1, wherein the ferritic stainless steel comprises, in percent by weight (wt%), 0.4 to 1.0% of Mn and 0.1 to 0.15% of Al.

3. A method of manufacturing a ferritic stainless steel with reduced grain boundary erosion, the method comprising:

   preparing a slab comprising, in percent by weight (wt%), 0.005 to 0.1% of C, 0.01 to 1.0% of Si, 0.01 to 1.5% of Mn, 13 to 18% of Cr, 0.005 to 0.1% of N, 0.005 to 0.2% of Al, 0.005 to 0.1% of Ni, 0.003% or less of Mo, 0.05% or less of P, 0.005% or less of S, and the remainder being Fe and impurities, and satisfying an Ac1, defined by Formula (1) below, of 900 or more and 990 or less;
   reheating the slab;
   rough-rolling the reheated slab and finish-rolling the rough-rolled steel material;
   coiling the hot-rolled steel material;
   continuous annealing the coiled steel material in a temperature range T(A) defined by Formula (2) below; and
   acid-pickling the continuous annealed steel material,

   $$\text{Formula (1): } Ac1 = 36Cr+90Si+76Mo+760Al+350-(800C+1300N+150Ni+50Mn)$$

   (wherein C, N, Si, Mn, Cr, Ni, Al, Mn, and Mo represent a content (wt%) of each element)

   $$\text{Formula (2): } 870°C \leq T(A) \leq (Ac1-10)°C$$

4. The method according to claim 3, wherein the slab comprises, in percent by weight (wt%), 0.4 to 1.0% of Mn and 0.1 to 0.15% of Al.

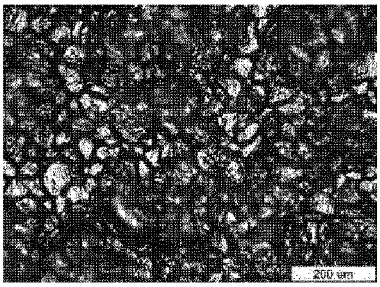
5. The method according to claim 3, wherein the reheating is performed in a temperature range of 1,000 to 1,200°C.

6. The method according to claim 3, wherein the finish rolling is performed in a temperature range of 800 to (Ac1-10)°C.

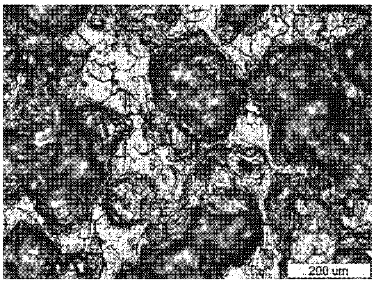
7. The method according to claim 3, wherein the coiling is performed in a temperature range of 750 to (Ac1-10)°C.

8. The method according to claim 3, wherein the continuous annealing is performed for 3 to 10 minutes.

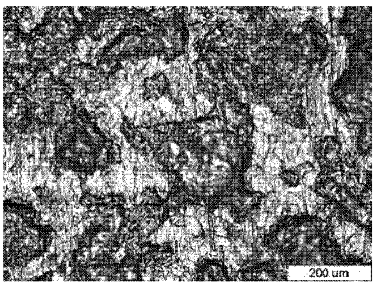
【FIG.1A】



【FIG.1B】



【FIG.1C】



INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2021/015393

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/04(2006.01)i; **C22C 38/06**(2006.01)i; **C22C 38/02**(2006.01)i; **C22C 38/00**(2006.01)i; **C22C 38/12**(2006.01)i; **C21D 8/02**(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/04(2006.01); B21B 45/04(2006.01); C21D 8/02(2006.01); C21D 9/46(2006.01); C22C 38/00(2006.01); C22C 38/18(2006.01); C22C 38/54(2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models: IPC as above
Japanese utility models and applications for utility models: IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS (KIPO internal) & keywords: 페라이트(ferrite), 스테인리스강(stainless steel), 연속소둔(continous annealing), 크롬(Cr), 몰리브덴(Mo)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2008-214649 A (JFE STEEL K.K.) 18 September 2008 (2008-09-18) See paragraphs [0032] and [0039]-[0040] and claims 1-3.	1-2
Y		3-8
Y	JP 09-111354 A (SUMITOMO METAL IND. LTD.) 28 April 1997 (1997-04-28) See paragraphs [0023]-[0025] and claim 1.	3-8
A	KR 10-2009-0067870 A (POSCO) 25 June 2009 (2009-06-25) See claim 1.	1-8
A	JP 2001-288543 A (NIPPON STEEL CORP.) 19 October 2001 (2001-10-19) See claims 1 and 5-7.	1-8
A	JP 2018-154857 A (NISSHIN STEEL CO., LTD.) 04 October 2018 (2018-10-04) See claims 1 and 6.	1-8

☐ Further documents are listed in the continuation of Box C.
☑ See patent family annex.

* Special categories of cited documents:
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"D" document cited by the applicant in the international application
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"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
04 March 2022	**04 March 2022**

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2021/015393

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JP 2018-154857 A	04 October 2018	JP 6878060 B2	26 May 2021

Form PCT/ISA/210 (patent family annex) (July 2019)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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