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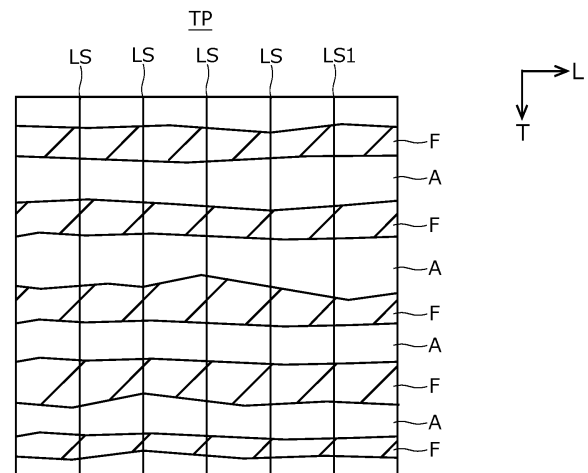
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(54) **DUPLEX STAINLESS STEEL MATERIAL**

(57) A duplex stainless steel material having excellent intergranular corrosion resistance is provided. The duplex stainless steel material according to the present disclosure consists of: in mass%, C: 0.030% or less, Si: 0.50% or less, Mn: 2.00% or less, P: 0.040% or less, S: 0.0010% or less, Cr: 26.0 to 28.0%, Ni: 6.0 to 10.0%, Mo: 0.20 to 1.70%, W: more than 2.00 to 3.00%, N: more than 0.30 to 0.40%, O: 0.020% or less, and Al: 0.050% or less, with the balance being Fe and impurities, and with a longitudinal direction being defined as an L direction and a thickness direction being defined as a T direction, when five line segments which divide each of three rectangular regions into six equal parts in the L direction are defined as line segments LS, a ferrite average thickness TF of each ferrite overlapping the 15 LS is 2.50 to 4.50 μm , a sample standard deviation ΔTF of ferrite thickness is 0.50 μm or less, and an austenite average thickness TA of each austenite overlapping the LS is 2.50 to 4.50 μm .

FIG.4



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Description

TECHNICAL FIELD

[0001] The present disclosure relates to a duplex stainless steel material.

BACKGROUND ART

[0002] In a urea plant, which is a type of chemical plants, urea is produced. In the urea plant, urea is produced by the following method. A mixed gas containing ammonia and carbon dioxide is synthesized at a high pressure of 120 kg/cm² or more in an elevated temperature range of 160 to 230°C. At this moment, urea is generated through a synthesis reaction.

[0003] In the above-described urea production process, an intermediate substance called ammonia carbamate is generated. Ammonia carbamate is highly corrosive and promotes intergranular corrosion of steel materials. Therefore, steel materials used in a urea plant are required to have excellent intergranular corrosion resistance.

[0004] A duplex stainless steel material has excellent corrosion resistance. Therefore, the duplex stainless steel material is utilized as a steel material for use in urea production plants. Duplex stainless steel materials for urea production plants have been proposed in, for example, Japanese Patent Application Publication No. 2003-301241 (Patent Literature 1) and Japanese Patent Application Publication No. 2011-127186 (Patent Literature 2).

[0005] A duplex stainless steel material disclosed in Patent Literature 1 attempts to improve corrosion resistance from the viewpoint of chemical composition. Specifically, it suppresses a content of Cu which increases the corrosion rate. Furthermore, it suppresses a content of Mo, which promotes the formation of a σ phase, and contains W, which is a ferrite stabilizing element to replace Mo and which does not promote the formation of the σ phase. Patent Literature 1 discloses that as a result, the corrosion resistance of the duplex stainless steel material is improved.

[0006] A duplex stainless steel material disclosed in Patent Literature 2 attempts to improve corrosion resistance from the viewpoint of chemical composition. Specifically, it defines a relational expression of Nd, P, S, Al and Mo contents and, by controlling the relational expression in a predetermined range, suppresses the formation of the σ phase at an interface between ferrite and austenite. Patent Literature 2 discloses that as a result, the corrosion resistance of the duplex stainless steel material is improved.

CITATION LIST

PATENT LITERATURES

[0007]

Patent Literature 1: Japanese Patent Application Publication No. 2003-301241

Patent Literature 2: Japanese Patent Application Publication No. 2011-127186

[0008] By the way, a duplex stainless steel material used in a urea production plant may be welded to form a welded joint during plant construction. In such a welded joint, a heat-affected zone (HAZ: Heat-Affected Zone) is formed in a base metal portion adjacent to weld metal. In the welded joint, intergranular corrosion is likely to proceed in the HAZ. Therefore, even when a duplex stainless steel material is used as the welded joint, it is required to have excellent intergranular corrosion resistance.

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0009] An objective of the present disclosure is to provide a duplex stainless steel material which has excellent intergranular corrosion resistance even when it is used as a welded joint.

SOLUTION TO PROBLEM

[0010] A duplex stainless steel material according to the present disclosure includes:

a chemical composition consisting of: in mass%,

C: 0.030% or less,

Si: 0.50% or less,
Mn: 2.00% or less,
P: 0.040% or less,
S: 0.0010% or less,
5 Cr: 26.0 to 28.0%,
Ni: 6.0 to 10.0%,
Mo: 0.20 to 1.70%,
W: more than 2.00 to 3.00%,
N: more than 0.30 to 0.40%,
10 O: 0.020% or less,
Al: 0.050% or less,
Cu: 0 to 0.30%,
Co: 0 to 1.0%,
Ti: 0 to 0.300%,
15 Nb: 0 to 0.300%,
Ca: 0 to 0.010%,
Mg: 0 to 0.010%, and
B: 0 to 0.010%, with the balance being Fe and impurities; wherein

20 with a longitudinal direction of the duplex stainless steel material being defined as an L direction, and a thickness direction of the duplex stainless steel material being defined as a T direction,
when, in a section including the L direction and the T direction of the duplex stainless steel material, three rectangular regions are identified at a pitch of 100 mm in the L direction, where each identified region is a rectangle of 200 μm in the L direction and 200 μm in the T direction, and
25 when, in each rectangular region,
five line segments, which extend in the T direction and are arranged at equal intervals in the L direction of the rectangular region, thereby dividing the rectangular region into six equal parts in the L direction, are defined as line segments LS,
a ferrite average thickness TF of each ferrite overlapping the 15 line segments LS of the three rectangular regions is
30 2.50 to 4.50 μm , and a sample standard deviation ΔTF of ferrite thickness is 0.50 μm or less, and
an austenite average thickness TA of each austenite overlapping the 15 line segments LS is 2.50 to 4.50 μm .

ADVANTAGEOUS EFFECT OF INVENTION

35 **[0011]** The duplex stainless steel material according to the present disclosure has excellent intergranular corrosion resistance even when it is used as a welded joint.

BRIEF DESCRIPTION OF DRAWINGS

40 **[0012]**

[FIG. 1] FIG. 1 is a schematic diagram of a longitudinal section including a longitudinal direction (L direction) and a thickness direction (T direction) of a duplex stainless steel material.

45 [FIG. 2] FIG. 2 is a schematic diagram of a longitudinal section of the duplex stainless steel material when the duplex stainless steel material is welded to form a welded joint.

[FIG. 3] FIG. 3 is a longitudinal sectional view of the duplex stainless steel material for explaining a method for identifying a rectangular region TP for measuring a ferrite average thickness TF of the duplex stainless steel material, a sample standard deviation ΔTF of ferrite thickness, and an austenite average thickness TA, when the duplex stainless steel material is a steel pipe.

50 [FIG. 4] FIG. 4 is a schematic diagram of the rectangular region TP in FIG. 3.

[FIG. 5] FIG. 5 is an enlarged diagram of a region of the rectangular region in FIG. 4 overlapping a line segment LS1.

DESCRIPTION OF EMBODIMENT

55 **[0013]** The present inventors have studied on a duplex stainless steel material having excellent intergranular corrosion resistance even when formed into a welded joint. As a result, the present inventors have obtained the following findings.

[0014] First, the present inventors studied on a duplex stainless steel material having excellent intergranular corrosion resistance even when it is a welded joint from the viewpoint of chemical composition in the same manner as Patent

Literatures 1 and 2. As a result, the present inventors considered that the duplex stainless steel material can achieve excellent intergranular corrosion resistance even when it is formed into a welded joint if the chemical composition thereof satisfies the following Feature 1.

(Feature 1)

[0015] The chemical composition consists of: in mass%, C: 0.030% or less, Si: 0.50% or less, Mn: 2.00% or less, P: 0.040% or less, S: 0.0010% or less, Cr: 26.0 to 28.0%, Ni: 6.0 to 10.0%, Mo: 0.20 to 1.70%, W: more than 2.00 to 3.00%, N: more than 0.30 to 0.40%, O: 0.020% or less, Al: 0.050% or less, Cu: 0 to 0.30%, Co: 0 to 1.0%, Ti: 0 to 0.300%, Nb: 0 to 0.300%, Ca: 0 to 0.010%, Mg: 0 to 0.010%, and B: 0 to 0.010%, with the balance being Fe and impurities.

[0016] Therefore, the present inventors further studied on a way by which the duplex stainless steel material can achieve sufficient intergranular corrosion resistance even when it is welded to form a welded joint. When the duplex stainless steel material is welded to form a welded joint, as described above, intergranular corrosion is likely to occur especially in a heat-affected zone (HAZ). Accordingly, when the duplex stainless steel material was formed into a welded joint, a microstructure at the HAZ and a microstructure at a base metal portion other than the HAZ were observed. As a result, the present inventors have obtained the following findings.

[0017] A microstructure of the duplex stainless steel material is substantially composed of ferrite and austenite. Specifically, in a section including a longitudinal direction (L direction) of the duplex stainless steel material and a thickness direction (T direction) of the duplex stainless steel material (hereafter also referred to as a longitudinal section), ferrite F and austenite A are stacked in layers as shown in FIG. 1.

[0018] When the duplex stainless steel material is welded to form a welded joint, the microstructure of the HAZ is also composed of ferrite and austenite. Comparing the microstructure of the HAZ in which intergranular corrosion occurred with the microstructure of the HAZ in which intergranular corrosion was not observed, a similar size of ferrite and austenite were observed both in the microstructure of the HAZ in which intergranular corrosion occurred and the microstructure of the HAZ in which intergranular corrosion was not observed. However, as shown in FIG. 2, further in the microstructure of the HAZ in which intergranular corrosion occurred, many particles of Cr nitride and secondary austenite MA were formed in ferrite F. Secondary austenite means austenite that is noticeably finer than the above-described austenite A. As a result of the investigation, it was found that such Cr nitride and secondary austenite MA are formed during welding.

[0019] Based on the above-described findings, the present inventors considered that factors that reduce the intergranular corrosiveness of the HAZ of the welded joint of the duplex stainless steel material are Cr nitride and secondary austenite formed during welding. Therefore, the present inventors have studied on a way to suppress amounts of Cr nitride and secondary austenite formed during welding. As a result, the present inventors have obtained the following findings.

[0020] As described above, Cr nitride and secondary austenite are formed from ferrite during welding. Therefore, if the thickness of ferrite (that is, a length in the T direction) is large in ferrite and austenite stacked in layers, a distance over which N, which has dissolved into the ferrite during welding, diffuses to austenite in a cooling process increases. In addition, in welding, a time available for diffusion is short due to the short cooling time. Therefore, Cr nitride is considered to be formed, and secondary austenite is likely to be formed during welding.

[0021] Furthermore, if there is a variation in the thickness of ferrite in the L direction in the longitudinal section of the duplex stainless steel material, it is considered that Cr nitride and secondary austenite are likely to be formed during welding in a wider portion (thicker portion) of ferrite extending in the L direction.

[0022] As described above, the present inventors have considered that to suppress the amounts of the formation of Cr nitride and secondary austenite during welding, it is effective to narrow the width (thickness) of ferrite and to reduce the variation in the width (thickness) of ferrite.

[0023] Accordingly, the microstructure of the duplex stainless steel material was further studied. As a result, it was found that the intergranular corrosion resistance of the HAZ when formed into the welded joint will be remarkably improved if the duplex stainless steel material satisfies the following feature.

(Feature 2)

[0024] It is defined such that the longitudinal direction of the duplex stainless steel material is the L direction, and the thickness direction of the duplex stainless steel material is the T direction. In a section including the L direction and the T direction of the duplex stainless steel material, three rectangular regions are identified at a pitch of 100 mm in the L direction. Each identified region is to be a rectangle which is of 200 μm in the L direction and 200 μm in the T direction. In each rectangular region, five line segments which extend in the T direction and are arranged at equal intervals in the L direction of the rectangular region, thereby dividing the rectangular region into six equal parts in the L direction, are defined as line segments LS. In this case, the following (1) to (3) are satisfied.

(1) The ferrite average thickness TF of each ferrite overlapping the 15 line segments LS of the three rectangular

regions is 2.50 to 4.50 μm .

(2) The sample standard deviation ΔTF of ferrite thickness is 0.50 μm or less.

(3) The austenite average thickness TA of each austenite overlapping the 15 line segments LS is 2.50 to 4.50 μm .

[0025] The duplex stainless steel material according to the present embodiment which has been completed based on the above-described findings has the following configuration.

[0026]

[1] The duplex stainless steel material of a first configuration includes:

a chemical composition consisting of: in mass%,

C: 0.030% or less,

Si: 0.50% or less,

Mn: 2.00% or less,

P: 0.040% or less,

S: 0.0010% or less,

Cr: 26.0 to 28.0%,

Ni: 6.0 to 10.0%,

Mo: 0.20 to 1.70%,

W: more than 2.00 to 3.00%,

N: more than 0.30 to 0.40%,

O: 0.020% or less,

Al: 0.050% or less,

Cu: 0 to 0.30%,

Co: 0 to 1.0%,

Ti: 0 to 0.300%,

Nb: 0 to 0.300%,

Ca: 0 to 0.010%,

Mg: 0 to 0.010%, and

B: 0 to 0.010%, with the balance being Fe and impurities; wherein

with a longitudinal direction of the duplex stainless steel material being defined as an L direction and a thickness direction of the duplex stainless steel material being defined as a T direction,

when, in a section including the L direction and the T direction of the duplex stainless steel material, three rectangular regions are identified at a pitch of 100 mm in the L direction, where each identified region is a rectangle of 200 μm in the L direction and 200 μm in the T direction, and

when, in each rectangular region,

five line segments, which extend in the T direction and are arranged at equal intervals in the L direction of the rectangular region, thereby dividing the rectangular region into six equal parts in the L direction, are defined as line segments LS,

a ferrite average thickness TF of each ferrite overlapping the 15 line segments LS of the three rectangular regions is 2.50 to 4.50 μm , and a sample standard deviation ΔTF of ferrite thickness is 0.50 μm or less, and

an austenite average thickness TA of each austenite overlapping the 15 line segments LS is 2.50 to 4.50 μm .

[2] The duplex stainless steel material of a second configuration is the duplex stainless steel material according to the first configuration, wherein

the chemical composition contains one or more elements selected from the group consisting of:

Cu: 0.01 to 0.30%,

Co: 0.1 to 1.0%,

Ti: 0.001 to 0.300%,

Nb: 0.001 to 0.300%,

Ca: 0.001 to 0.010%,

Mg: 0.001 to 0.010%, and

B: 0.001 to 0.010%.

[3] The duplex stainless steel material of a third configuration is the duplex stainless steel material according to the first

or the second configuration, wherein the duplex stainless steel material is a seamless steel pipe.

[0027] Hereafter, the duplex stainless steel material of the present embodiment will be described in detail. Note that unless otherwise stated, "%" relating to elements means mass%.

[Features of duplex stainless steel material of present embodiment]

[0028] The duplex stainless steel material of the present embodiment satisfies the following Feature 1 and Feature 2.

(Feature 1)

[0029] The chemical composition consists of: in mass%, C: 0.030% or less, Si: 0.50% or less, Mn: 2.00% or less, P: 0.040% or less, S: 0.0010% or less, Cr: 26.0 to 28.0%, Ni: 6.0 to 10.0%, Mo: 0.20 to 1.70%, W: more than 2.00 to 3.00%, N: more than 0.30 to 0.40%, O: 0.020% or less, Al: 0.050% or less, Cu: 0 to 0.30%, Co: 0 to 1.0%, Ti: 0 to 0.300%, Nb: 0 to 0.300%, Ca: 0 to 0.010%, Mg: 0 to 0.010%, and B: 0 to 0.010%, with the balance being Fe and impurities.

(Feature 2)

[0030] It is defined such that the longitudinal direction of the duplex stainless steel material is the L direction, and the thickness direction of the duplex stainless steel material is the T direction. In the section including the L direction and the T direction of the duplex stainless steel material, the three rectangular regions are identified at a pitch of 100 mm in the L direction. Each identified region is to be the rectangle which is of 200 μm in the L direction and 200 μm in the T direction. In each rectangular region, the five line segments which extend in the T direction and are arranged at equal intervals in the L direction of the rectangular region, and which divide the rectangular region into six equal parts in the L direction, are defined as the line segments LS. In this case, the following (1) to (3) are satisfied.

(1) The ferrite average thickness TF of each ferrite overlapping the 15 line segments LS of the three rectangular regions is 2.50 to 4.50 μm .

(2) The sample standard deviation ΔTF of ferrite thickness is 0.50 μm or less.

(3) The austenite average thickness TA of each austenite overlapping the 15 line segments LS is 2.50 to 4.50 μm .

[0031] Hereafter, Feature 1 and Feature 2 will be described.

[(Feature 1) Chemical composition]

[0032] The chemical composition of the duplex stainless steel material of the present embodiment contains the following elements.

C: 0.030% or less

[0033] Carbon (C) is unavoidably contained. That is the C content is more than 0%. Carbon forms carbide, thereby increasing the strength of steel materials. However, if the C content is more than 0.030%, Cr carbide is formed at grain boundaries. In this case, the intergranular corrosion resistance of the steel material will deteriorate even if contents of other elements are within the range of the present embodiment.

[0034] Therefore, the C content is 0.030% or less.

[0035] The C content is preferably as low as possible. However, excessive reduction of the C content will significantly increase the production cost. Therefore, when industrial manufacturing is taken into consideration, a lower limit of the C content is preferably 0.001%, more preferably 0.002% and further preferably 0.005%.

[0036] An upper limit of the C content is preferably 0.028%, more preferably 0.025%, further preferably 0.022%, and further preferably 0.020%.

Si: 0.50% or less

[0037] Silicon (Si) is unavoidably contained. That is, the Si content is more than 0%. Si deoxidizes steel in the steelmaking stage during production process of the steel material.

[0038] On the other hand, if the Si content is more than 0.50%, Si segregates at grain boundaries. In this case, the intergranular corrosion resistance of the steel material will deteriorate even if the contents of other elements are within the range of the present embodiment.

[0039] Therefore, the Si content is 0.50% or less.

[0040] A lower limit of the Si content is preferably 0.01%, more preferably 0.02%, and further preferably 0.05%.

[0041] An upper limit of the Si content is preferably 0.45%, more preferably 0.40%, further preferably 0.38%, and further preferably 0.35%.

Mn: 2.00% or less

[0042] Manganese (Mn) is unavoidably contained. That is, the Mn content is more than 0%. Mn deoxidizes steel in the steelmaking stage during production process of the steel material. Further, Mn is an austenite forming element, and stabilizes austenite in the steel material. If even a small amount of Mn is contained, the above-described effect can be obtained to some extent.

[0043] However, if the Mn content is more than 2.00%, Mn segregates at grain boundaries together with impurities such as P and S. In this case, the corrosion resistance of the steel material will deteriorate in a high-temperature environment, even if the contents of other elements are within the range of the present embodiment.

[0044] Therefore, the Mn content is 2.00% or less.

[0045] A lower limit of the Mn content is preferably 0.01%, more preferably 0.05%, and further preferably 0.10%.

[0046] An upper limit of the Mn content is preferably 1.60%, more preferably 1.40%, further preferably 1.20%, further preferably 1.00%, further preferably 0.90%, further preferably 0.80%, and further preferably 0.70%.

P: 0.040% or less

[0047] Phosphorus (P) is an impurity, and the P content is more than 0%. If the P content is more than 0.040%, P segregates at grain boundaries even if the contents of other elements are within the range of the present embodiment. For that reason, the intergranular corrosion resistance of the steel material will deteriorate.

[0048] Therefore, the P content is 0.040% or less.

[0049] The P content is preferably as low as possible. However, excessive reduction of the P content will significantly increase the production cost. Therefore, when industrial manufacturing is taken into consideration, a lower limit of the P content is preferably 0.001%, more preferably 0.002%, and further preferably 0.005%.

[0050] An upper limit of the P content is preferably 0.035%, more preferably 0.030%, further preferably 0.025%, further preferably 0.020%, and further preferably 0.015%.

S: 0.0010% or less

[0051] Sulfur (S) is an impurity, and the S content is more than 0%. If the S content is more than 0.0010%, S segregates at grain boundaries even if the contents of other elements are within the range of the present embodiment. For that reason, the intergranular corrosion resistance of the steel material will deteriorate.

[0052] Therefore, the S content is 0.0010% or less.

[0053] The S content is preferably as low as possible. However, excessive reduction of the S content will significantly increase the production cost. Therefore, when industrial manufacturing is taken into consideration, a lower limit of the S content is preferably 0.0001%, and more preferably 0.0002%.

[0054] An upper limit of the S content is preferably 0.0009%, more preferably 0.0007%, and further preferably 0.0005%.

Cr: 26.0 to 28.0%

[0055] Chromium (Cr) dissolves into steel material thereby improving the intergranular corrosion resistance thereof. Further, Cr stabilizes ferrite in steel materials, thereby improving the intergranular corrosion resistance of the steel materials. If the Cr content is less than 26.0%, the above-described effects cannot be obtained sufficiently even if the contents of other elements are within the range of the present embodiment.

[0056] On the other hand, if the Cr content is more than 28.0%, a sigma (σ) phase is formed in the steel material even if the contents of other elements are within the range of the present embodiment. The σ phase deteriorates the intergranular corrosion resistance of the steel material.

[0057] Therefore, the Cr content is 26.0 to 28.0%.

[0058] A lower limit of the Cr content is preferably 26.1%, more preferably 26.2%, further preferably 26.3%, and further preferably 26.4%.

[0059] An upper limit of the Cr content is preferably 27.9%, more preferably 27.8%, further preferably 27.7%, and further preferably 27.6%.

Ni: 6.0 to 10.0%

[0060] Nickel (Ni) stabilizes austenite in steel materials. That is, Ni stabilizes a duplex structure of ferrite and austenite. For that reason, the intergranular corrosion resistance of the steel material is improved. If the Ni content is less than 6.0%, the above-described effect cannot be obtained sufficiently even if the contents of other elements are within the range of the present embodiment.

[0061] On the other hand, if the Ni content is more than 10.0%, the fraction of austenite in the steel material become excessively high even if the contents of other elements are within the range of the present embodiment. In this case, the intergranular corrosion resistance will deteriorate.

[0062] Therefore, the Ni content is 6.0 to 10.0%.

[0063] A lower limit of the Ni content is preferably 6.2%, more preferably 6.3%, further preferably 6.4%, and further preferably 6.5%.

[0064] An upper limit of the Ni content is preferably 9.5%, more preferably 9.0%, further preferably 8.5%, and further preferably 8.0%.

Mo: 0.20 to 1.70%

[0065] Molybdenum (Mo) improves the intergranular corrosion resistance of steel materials. If the Mo content is less than 0.20%, the above-described effect cannot be obtained sufficiently even if the contents of other elements are within the range of the present embodiment.

[0066] On the other hand, if the Mo content is more than 1.70%, the σ phase is formed even if the contents of other elements are within the range of the present embodiment. In this case, the intergranular corrosion resistance of the steel material will deteriorate.

[0067] Therefore, the Mo content is 0.20 to 1.70%.

[0068] A lower limit of the Mo content is preferably 0.30%, more preferably 0.40%, and further preferably 0.50%.

[0069] An upper limit of the Mo content is preferably 1.60%, more preferably 1.50%, further preferably 1.40%, further preferably 1.30%, further preferably 1.20%, further preferably 1.10%, and further preferably 1.00%.

W: more than 2.00 to 3.00%

[0070] Tungsten (W) improves the intergranular corrosion resistance of steel materials. If the W content is 2.00% or less, the above-described effect cannot be obtained sufficiently even if the contents of other elements are within the range of the present embodiment.

[0071] On the other hand, if the W content is more than 3.00%, the σ phase is formed even if the contents of other elements are within the range of the present embodiment. In this case, the intergranular corrosion resistance of the steel material will deteriorate.

[0072] Therefore, the W content is more than 2.00 to 3.00%.

[0073] A lower limit of the W content is preferably 2.01%, more preferably 2.02%, further preferably 2.05%, further preferably 2.08%, further preferably 2.10%, and further preferably 2.12%.

[0074] An upper limit of the W content is preferably 2.90%, more preferably 2.80%, further preferably 2.70%, further preferably 2.60%, further preferably 2.50%, further preferably 2.40%, and further preferably 2.30%.

N: more than 0.30 to 0.40%

[0075] Nitrogen (N) stabilizes austenite in steel materials. That is, N stabilizes the duplex structure of ferrite and austenite. For that reason, the intergranular corrosion resistance of the steel material is improved. If the N content is 0.30% or less, the above-described effect cannot be obtained sufficiently even if the contents of other elements are within the range of the present embodiment.

[0076] On the other hand, if the N content is more than 0.40%, the hot workability of the steel material will deteriorate even if the contents of other elements are within the range of the present embodiment.

[0077] Therefore, the N content is more than 0.30 to 0.40%.

[0078] A lower limit of the N content is preferably 0.31%, and more preferably 0.32%.

[0079] An upper limit of the N content is preferably 0.39%, more preferably 0.38%, and further preferably 0.37%.

O: 0.020% or less

[0080] Oxygen (O) is an impurity, and the O content is more than 0%. If the O content is more than 0.020%, oxides are excessively formed in the steel material. In this case, the intergranular corrosion resistance of the steel material will

deteriorate even if the contents of other elements are within the range of the present embodiment.

[0081] Therefore, the O content is 0.020% or less.

[0082] The O content is preferably as low as possible. However, excessive reduction of the O content will significantly increase the production cost. Therefore, when industrial manufacturing is taken into consideration, a lower limit of the O content is preferably 0.001%, more preferably 0.002%, and further preferably 0.005%.

[0083] An upper limit of the O content is preferably 0.018%, more preferably 0.016%, and further preferably 0.014%.

Al: 0.050% or less

[0084] Aluminum (Al) is unavoidably contained. That is the Al content is more than 0%. Al deoxidizes steel materials. However, if the Al content is more than 0.050%, an excess amount of oxide will be formed in the steel material. In this case, the intergranular corrosion resistance of the steel material will deteriorate even if the contents of other elements are within the range of the present embodiment.

[0085] Therefore, the Al content is 0.050% or less.

[0086] A lower limit of the Al content is preferably 0.001%, more preferably 0.003%, and further preferably 0.005%.

[0087] An upper limit of the Al content is preferably 0.045%, more preferably 0.040%, further preferably 0.038%, and further preferably 0.036%.

[0088] Note that in the chemical composition of the duplex stainless steel material of the present embodiment, an Al content means the content of "acid-soluble Al", that is, sol. Al.

[0089] The balance of the chemical composition of the duplex stainless steel material according to the present embodiment is Fe and impurities. Here, impurities in the chemical composition means those which are not intentionally contained but are mixed from ores and scraps as a raw material or from a production environment when the duplex stainless steel material is industrially produced, and which are permitted within a range not adversely affecting the duplex stainless steel material of the present embodiment.

[Optional elements]

[0090] The chemical composition of the duplex stainless steel material of the present embodiment may further contain one or more elements selected from the group consisting of:

Cu: 0 to 0.30%,

Co: 0 to 1.0%,

Ti: 0 to 0.300%,

Nb: 0 to 0.300%,

Ca: 0 to 0.010%,

Mg: 0 to 0.010%, and

B: 0 to 0.010%.

[0091] Hereafter, these optional elements will be described.

[First group: Cu and Co]

[0092] The chemical composition of the duplex stainless steel material according to the present embodiment may further contain one or more elements selected from the group consisting of Cu and Co in place of part of Fe. Any of these elements is optional and may not be contained. If contained, Cu and Co improve the intergranular corrosion resistance of the steel material.

Cu: 0 to 0.30%

[0093] Copper (Cu) is an optional element and may not be contained. That is, the Cu content may be 0%.

[0094] When Cu is contained, that is, when the Cu content is more than 0%, Cu strengthens a passivation film, thereby improving the corrosion resistance of the duplex stainless steel material. Further, Cu stabilizes austenite. If even a small amount of Cu is contained, the above-described effects can be obtained to some extent.

[0095] However, if the Cu content is more than 0.30%, corrosion of the duplex stainless steel material will be promoted in the corrosive environment of a urea production plant even if the contents of other elements are within the range of the present embodiment.

[0096] Therefore, the Cu content is 0 to 0.30%.

[0097] A lower limit of the Cu content is preferably 0.01%, and more preferably 0.05%.

[0098] An upper limit of the Cu content is preferably 0.29%, more preferably 0.27%, further preferably 0.25%, and further preferably 0.22%.

Co: 0 to 1.0%

[0099] Cobalt (Co) is an optional element and may not be contained. That is, the Co content may be 0%.

[0100] When Co is contained, that is, when the Co content is more than 0%, Co strengthens the passivation film, thereby improving the corrosion resistance of the duplex stainless steel material. Further, Co stabilizes austenite. If even a small amount of Co is contained, the above-described effect can be obtained to some extent.

[0101] However, if the Co content is more than 1.0%, production cost will extremely increase even if the contents of other elements are within the range of the present embodiment.

[0102] Therefore, the Co content is 0 to 1.0%.

[0103] A lower limit of the Co content is preferably 0.1%, more preferably 0.2%, and further preferably 0.3%.

[0104] An upper limit of the Co content is preferably 0.9%, more preferably 0.8%, and further preferably 0.7%.

[Second group: Ti and Nb]

[0105] The chemical composition of the duplex stainless steel material according to the present embodiment may further contain one or more elements selected from the group consisting of Ti and Nb in place of part of Fe. Any of these elements is optional and may not be contained. If contained, Ti and Nb increase the strength of the steel material.

Ti: 0 to 0.300%

[0106] Titanium (Ti) is an optional element and may not be contained. That is, the Ti content may be 0%.

[0107] When Ti is contained, that is, when the Ti content is more than 0%, Ti forms carbonitride and thereby increases the strength of the steel material. Further, Ti suppresses the formation of Cr carbonitride by forming carbonitride. For that reason, the intergranular corrosion resistance of the steel material is improved. If even a small amount of Ti is contained, the above-described effect can be obtained to some extent.

[0108] However, if the Ti content is more than 0.300%, the strength of the steel material becomes excessively high, thereby deteriorating the toughness of the steel material even if the contents of other elements are within the range of the present embodiment.

[0109] Therefore, the Ti content is 0 to 0.300%.

[0110] A lower limit of the Ti content is preferably 0.001%, more preferably 0.005%, further preferably 0.010%, further preferably 0.015%, and further preferably 0.020%.

[0111] An upper limit of the Ti content is preferably 0.250%, more preferably 0.200%, further preferably 0.150%, further preferably 0.100%, further preferably 0.090%, further preferably 0.080%, and further preferably 0.070%.

Nb: 0 to 0.300%

[0112] Niobium (Nb) is an optional element and may not be contained. That is, the Nb content may be 0%.

[0113] When Nb is contained, that is, when the Nb content is more than 0%, Nb forms carbonitride and thereby increases the strength of the steel material. Further, Nb suppresses the formation of Cr carbonitride by forming carbonitride. For that reason, the intergranular corrosion resistance of the steel material is improved. If even a small amount of Nb is contained, the above-described effect can be obtained to some extent.

[0114] However, if the Nb content is more than 0.300%, the strength of the steel material becomes excessively high, thereby deteriorating the toughness of the steel material even if the contents of other elements are within the range of the present embodiment.

[0115] Therefore, the Nb content is 0 to 0.300%.

[0116] A lower limit of the Nb content is preferably 0.001%, more preferably 0.005%, further preferably 0.010%, further preferably 0.015%, and further preferably 0.020%.

[0117] An upper limit of the Nb content is preferably 0.250%, more preferably 0.200%, further preferably 0.150%, further preferably 0.120%, further preferably 0.110%, and further preferably 0.100%.

[Third group: Ca, Mg, and B]

[0118] The chemical composition of the duplex stainless steel material according to the present embodiment may further contain one or more elements selected from the group consisting of Ca, Mg, and B in place of part of Fe. Any of these elements is optional and may not be contained. If contained, Ca, Mg, and B improves hot workability of the steel material.

Ca: 0 to 0.010%

[0119] Calcium (Ca) is an optional element and may not be contained. That is, the Ca content may be 0%.

[0120] When Ca is contained, that is, when the Ca content is more than 0%, Ca immobilizes S in the steel material as sulfide to make it harmless, and thereby improves the hot workability of the steel material. If even a small amount of Ca is contained, the above-described effect can be obtained to some extent.

[0121] However, if the Ca content is more than 0.010%, the oxide in the steel material becomes coarse and the toughness of the steel material deteriorates even if the contents of other elements are within the range of the present embodiment.

[0122] Therefore, the Ca content is 0 to 0.010%.

[0123] A lower limit of the Ca content is preferably 0.001%, and more preferably 0.002%.

[0124] An upper limit of the Ca content is preferably 0.009%, more preferably 0.008%, further preferably 0.007%, further preferably 0.006%, and further preferably 0.005%.

Mg: 0 to 0.010%

[0125] Magnesium (Mg) is an optional element and may not be contained. That is, the Mg content may be 0%.

[0126] When Mg is contained, that is, when the Mg content is more than 0%, Mg immobilizes S in the steel material as sulfide to make it harmless, and thereby improves the hot workability of the steel material. If even a small amount of Mg is contained, the above-described effect can be obtained to some extent.

[0127] However, if the Mg content is more than 0.010%, the oxide in the steel material becomes coarse and the toughness of the steel material deteriorates even if the contents of other elements are within the range of the present embodiment.

[0128] Therefore, the Mg content is 0 to 0.010%.

[0129] A lower limit of the Mg content is preferably 0.001%, and more preferably 0.002%.

[0130] An upper limit of the Mg content is preferably 0.009%, more preferably 0.008%, further preferably 0.007%, further preferably 0.006%, and further preferably 0.005%.

B: 0 to 0.010%

[0131] Boron (B) is an optional element and may not be contained. That is, the B content may be 0%.

[0132] When B is contained, that is, when the B content is more than 0%, B suppresses segregation of S at grain boundaries in the steel material, and thereby improves the hot workability of the steel material. If B is contained even in a small amount, the above-described effect can be obtained to some extent.

[0133] However, if the B content is more than 0.010%, boron nitride (BN) is formed, thereby deteriorating the toughness of the steel material even if the contents of other elements are within the range of the present embodiment.

[0134] Therefore, the B content is 0 to 0.010%.

[0135] A lower limit of the B content is preferably 0.001%, and more preferably 0.002%.

[0136] An upper limit of the B content is preferably 0.009%, more preferably 0.008%, further preferably 0.007%, further preferably 0.006%, further preferably 0.005%, and further preferably 0.004%.

[Microstructure]

[0137] The microstructure of the duplex stainless steel material according to the present embodiment is composed of ferrite and austenite. As used herein, "composed of ferrite and austenite" means that the amounts of phases other than ferrite and austenite are negligibly small. The microstructure of the duplex stainless steel material according to the present embodiment may contain a minute amount of precipitates and inclusions in addition to ferrite and austenite. The area fractions of precipitates and inclusions in the microstructure of the duplex stainless steel material according to the present embodiment is negligibly low compared with the area fractions of ferrite and austenite.

[0138] In the microstructure of the duplex stainless steel material according to the present embodiment, the area fraction of ferrite is 35 to 55%. A lower limit of the area fraction of ferrite is preferably 37%, and more preferably 39%. An upper limit of the area fraction of ferrite is preferably 53%, and more preferably 51%.

[Measurement method of ferrite area fraction]

[0139] In the present embodiment, the area fraction of ferrite of the duplex stainless steel material can be determined by the following method.

[0140] It is defined such that the longitudinal direction of the duplex stainless steel material according to the present

embodiment is the L direction, and the thickness direction thereof is the T direction. Specifically, when the duplex stainless steel material is a steel pipe, a pipe axis direction (rolling direction) is the L direction, and a wall thickness direction is the T direction. When the duplex stainless steel material is a steel plate, a longitudinal direction (rolling direction) is the L direction, and a plate thickness direction is the T direction. When the duplex stainless steel material is a steel bar, a central axis direction (longitudinal direction) is the L direction, and a radial direction is the T direction.

[0141] A test specimen with a surface, which includes a longitudinal section including the L direction and the T direction, is collected from a middle part of the thickness of the duplex stainless steel material. When the duplex stainless steel material is a steel pipe, a test specimen is collected from a middle part of the wall thickness. When the duplex stainless steel material is a steel plate, a test specimen is collected from a central part of the plate thickness. When the duplex stainless steel material is a steel bar, a test specimen is collected from a central part of a section perpendicular to the L direction.

[0142] Out of the surfaces of the test specimen, the surface corresponding to the longitudinal section (plane including the L direction and the T direction) is defined as an observation surface. Note that the size of the test specimen is not particularly limited and it suffices that an observation surface of 5 mm in the L direction and 5 mm in the T direction is obtained.

[0143] The observation surface of the test specimen is mirror polished. The mirror-polished observation surface is subjected to electrolytic etching in a 30% sodium hydroxide etching reagent to reveal microstructure. The observation surface on which the microstructure has been revealed is observed in 10 fields of view using an optical microscope. The area of the observation field is not particularly limited, but is, for example, $4.00 \times 10^4 \mu\text{m}^2$ (at a magnification of 500 times).

[0144] In each field of view, ferrite and austenite are identified from contrast. Area fractions of the identified ferrite and austenite are determined. The method for determining the area fractions of identified ferrite and austenite is not particularly limited, and a well-known method may be used. For example, the area fractions of ferrite and austenite can be determined by image analysis. In the present embodiment, an arithmetic average value of the area fractions of ferrite determined in all the fields of view is defined as a ferrite area fraction (%). It is noted that the ferrite area fraction is an integer obtained by rounding the first decimal place. Further, the austenite area fraction (%) is obtained by the following formula.

$$\text{Austenite area fraction} = 100 - \text{ferrite area fraction}$$

[(Feature 2) Ferrite average thickness TF, sample standard deviation ΔTF , austenite average thickness TA]

[0145] It is defined such that the longitudinal direction of the duplex stainless steel material is the L direction, and the thickness direction of the duplex stainless steel material is the T direction. In the section including the L direction and the T direction of the duplex stainless steel material, three rectangular regions are identified at a pitch of 100 mm in the L direction. Each identified region is to be a rectangle which is of 200 μm in the L direction and 200 μm in the T direction. In each rectangular region, five line segments, which extend in the T direction and are arranged at equal intervals in the L direction of the rectangular region, thereby dividing the rectangular region into six equal parts in the L direction, are defined as line segments LS. In this case, the duplex stainless steel material of the present embodiment satisfies the following (1) to (3).

- (1) The ferrite average thickness TF of each ferrite overlapping the 15 line segments LS of the three rectangular regions is 2.50 to 4.50 μm .
- (2) The sample standard deviation ΔTF of ferrite thickness is 0.50 μm or less.
- (3) The austenite average thickness TA of each austenite overlapping the 15 line segments LS is 2.50 to 4.50 μm .

[0146] Hereafter, Feature 2 will be described in detail.

[Measurement method of ferrite average thickness TF, sample standard deviation ΔTF of ferrite thickness, and austenite average thickness TA]

[0147] The ferrite average thickness TF, the sample standard deviation ΔTF of ferrite thickness, and the austenite average thickness TA can be measured by the following method.

[0148] A test specimen with a surface, which includes a longitudinal section including the L direction and the T direction, is collected from a middle part of the thickness of the duplex stainless steel material.

[0149] FIG. 3 is a longitudinal sectional view for explaining a location of specimen collection when the duplex stainless steel material is a steel pipe. The dashed line C1 in FIG. 3 is a pipe axis. The dashed line L1 is a dashed line passing through a middle part of the wall thickness of the steel pipe. With reference to FIG. 3, when the duplex stainless steel material is the steel pipe, in a section (longitudinal section) including the L direction and the T direction, three rectangular regions TP are identified in a middle part of the wall thickness, and at a pitch of $P = 100 \text{ mm}$ in the L direction. Then, three test specimens,

each of which includes the rectangular region TP at its surface, are collected. The rectangular region TP is of 200 μm in the L direction and 200 μm in the T direction.

[0150] Similarly, when the duplex stainless steel material is a steel plate, in a longitudinal section including the L direction (rolling direction) and the T direction (plate thickness direction), three rectangular regions TP are identified in a middle part of the plate thickness and at a pitch of 100 mm in the L direction. Then, three test specimens, each of which includes the rectangular region TP at its surface, are collected.

[0151] Similarly, when the duplex stainless steel material is a steel bar, in a longitudinal section including the L direction (central axis direction) and the T direction (radial direction), three rectangular regions TP are identified in a central part in the radial direction (that is, at the central axis) and at a pitch of 100 mm in the L direction. Then, three test specimens, each of which includes the rectangular region TP at its surface, are collected.

[0152] Out of surfaces of the test specimen, a surface which includes the rectangular region TP is defined as an observation surface. It is noted that the size of the test specimen is not particularly limited, and it suffices that it can contain the rectangular region TP.

[0153] The observation surface of the test specimen is mirror polished. The mirror-polished observation surface is subjected to electrolytic etching in a 30% sodium hydroxide etching reagent to reveal microstructure. The rectangular region TP of the observation surface is observed at a magnification of 500 times by using an optical microscope.

[0154] FIG. 4 is a schematic diagram of the rectangular region TP. With reference to FIG. 4, the rectangular region is a rectangle of 200 μm in the L direction and 200 μm in the T direction. In the rectangular region TP, five line segments LS, which are arranged at an equal interval, and each divide the rectangular region TP into six equal parts in the L direction, are disposed. At this moment, each line segment LS overlaps ferrite F and austenite A in the rectangular region TP.

[0155] FIG. 5 is an enlarged view of a region of the rectangular region TP in FIG. 4 that overlaps the line segment LS1. With reference to FIG. 5, the line segment LS1 overlaps ferrite F1 to F5 and austenite A1 to A5. Here, the length of the ferrite F1 overlapping the line segment LS1 is defined as the thickness TF1 of the ferrite F1, and the thickness TF1 is determined. Similarly, the thicknesses TF2 to TF5 of the ferrite F2 to F5 overlapping the line segment LS1 is determined. Similarly, the thicknesses TA1 to TA6 of austenite A1 to A6 overlapping the line segment LS1 is determined.

[0156] Similarly, for the other four line segments LS of FIG. 4, the length over which the ferrite F overlaps the line segment LS is defined as the thickness of the concerned ferrite F. The length over which the austenite A overlaps the line segment LS is defined as the thickness of the concerned austenite A.

[0157] By the method described above, the thickness TF of each ferrite F that overlaps the 15 line segments of the three rectangular regions TP, and the thickness TA of each austenite A are determined. An arithmetic average value of all the determined thicknesses of ferrite is defined as the ferrite average thickness TF (μm). Based on the determined thicknesses of ferrite and the ferrite average thickness TF, the sample standard deviation ΔTF (μm) is determined.

[0158] Further, an arithmetic average value of all the determined thicknesses of austenite is defined as the austenite average thickness TA (μm).

[(1) to (3) of Feature 2]

[0159] The ferrite average thickness TF, the sample standard deviation ΔTF of ferrite thickness, and the austenite average thickness TA, which are obtained by the method described above, satisfy the following (1) to (3).

(1) The ferrite average thickness TF of each ferrite overlapping the 15 line segments LS of the three rectangular regions is 2.50 to 4.50 μm .

(2) The sample standard deviation ΔTF of ferrite thickness is 0.50 μm or less.

(3) The austenite average thickness TA of each austenite overlapping the 15 line segments LS is 2.50 to 4.50 μm .

[0160] If the ferrite average thickness TF is more than 4.50 μm , the thickness of ferrite will be excessively large. In this case, when the duplex stainless steel material is welded to form the welded joint, Cr nitride and secondary austenite are likely to be formed in the HAZ. As a result of that, the intergranular corrosion resistance when formed into the welded joint will deteriorate. If the ferrite average thickness TF is 4.50 μm or less, the thickness of ferrite is sufficiently small. For that reason, sufficient intergranular corrosion resistance can be achieved even when formed into the welded joint.

[0161] A lower limit of the ferrite average thickness TF is not particularly limited. A lower limit of the ferrite average thickness TF is, for example, 2.50 μm .

[0162] An upper limit of the ferrite average thickness TF is preferably 4.45 μm , more preferably 4.40 μm , and further preferably 4.35 μm .

[0163] A lower limit of the ferrite average thickness TF is preferably 2.55 μm , and more preferably 2.60 μm .

[0164] It is noted that if the ferrite average thickness TF is 2.50 to 4.50 μm , the austenite average thickness TA will be 2.50 to 4.50 μm .

[0165] An upper limit of the austenite average thickness TA is preferably 4.45 μm , more preferably 4.40 μm , and further

preferably 4.35 μm .

[0166] A lower limit of the austenite average thickness TA is preferably 2.55 μm , and more preferably 2.60 μm .

[0167] Further, regarding the ferrite, the sample standard deviation ΔTF of ferrite thickness is 0.50 μm or less. As described above, even if the ferrite average thickness TF is sufficiently small, if the variation of ferrite thickness in the L direction of the duplex stainless steel material is large, a portion of ferrite which is locally thick may exist in ferrite extending in the L direction. In this case, Cr nitrides and secondary austenite are likely to be formed during welding in the concerned portion which is locally thick. For that reason, when formed into the welded joint, the intergranular corrosion resistance deteriorates.

[0168] If the sample standard deviation ΔTF of ferrite thickness is 0.50 μm or less, the variation of the thickness of ferrite in the L direction is sufficiently small. Therefore, on the premise that the above-described (1) and (3) are satisfied, sufficient intergranular corrosion resistance can be achieved when formed into the welded joint.

[0169] An upper limit of the sample standard deviation ΔTF is preferably 0.48 μm , more preferably 0.45 μm , and further preferably 0.43 μm .

[Advantageous effect of the duplex stainless steel material of the present embodiment]

[0170] The duplex stainless steel material of the present embodiment satisfies Feature 1 and Feature 2. For that reason, the duplex stainless steel material of the present embodiment can achieve excellent intergranular corrosion resistance even when formed into the welded joint.

[Intergranular corrosion resistance]

[0171] In the duplex stainless steel material of the present embodiment, a statement "sufficient intergranular corrosion resistance can be achieved when formed into the welded joint" means that a corrosion rate obtained by performing the ASTM A262 Practice C nitric acid corrosion test on the welded joint whose base metal is the duplex stainless steel material of the present embodiment is 0.100 $\text{g}/\text{m}^2/\text{h}$ or less.

[Intergranular corrosion resistance evaluation method]

[0172] The intergranular corrosion resistance of the duplex stainless steel material of the present embodiment can be evaluated by the following method.

[0173] First, a welded joint of the duplex stainless steel material is produced. Specifically, a pair of duplex stainless steel materials are prepared. A weld groove is formed at an end of each prepared duplex stainless steel material. A shape of the weld groove is a U-type groove having a groove angle of 20 degrees. The weld grooves of the pair of duplex stainless steel materials are butted and welded. A welding material chemical composition that satisfies the above-described Feature 1 is prepared. With the prepared welding material, the pair of duplex stainless steel materials are welded by automatic gas tungsten arc welding (GTAW). An amount of heat input at this moment is 0.5 to 4.00 kJ/mm . From the produced welded joint of the duplex stainless steel material, a test specimen which contains a welded part in its middle part is collected. Specifically, a test specimen extending in a direction perpendicular to an extending direction of the welded part of the welded joint of the duplex stainless steel material is collected. The size of the test specimen is 2 mm thick $\times$ 10 mm wide $\times$ 40 mm long. The test specimen is collected such that the weld metal is placed at the middle part in the longitudinal direction of the test specimen. It is noted that the test specimen is collected such that the maximum width of the weld metal in the longitudinal direction of the test specimen is 25 mm or less.

[0174] Using the collected test specimens, the ASTM A262 Practice C nitric acid corrosion test is performed. Specifically, a test solution which is an aqueous solution whose concentration of nitric acid is 65 mass% is prepared. The test specimen is immersed in a boiling test solution for 48 hours (first immersion test). After the end of the test, a new test solution is prepared and, as in the first time, an immersion test is performed. Specifically, the test specimen is taken out from the test solution used for the first immersion test, and the test specimen is immersed in the test solution for the second immersion test for 48 hours. The immersion test as described above is repeated 10 times (1st to 10th).

[0175] Before and after each immersion test (1st to 10th), the mass of the test specimen is measured, and the difference (mass loss) is determined. Based on the mass loss, for each immersion test, mass loss in unit time per unit area of the test specimen (in $\text{g}/\text{m}^2/\text{h}$, hereafter referred to as a unit mass loss) is determined. The arithmetic average value of the determined unit mass loss of 10 times (1st to 10th) is defined as the corrosion rate ($\text{g}/\text{m}^2/\text{h}$).

[0176] If the obtained corrosion rate is 0.100 $\text{g}/\text{m}^2/\text{h}$ or less, it is judged that sufficient intergranular corrosion resistance has been obtained when formed into the welded joint.

[Shape of duplex stainless steel material of present embodiment]

[0177] As described above, the duplex stainless steel material of the present embodiment may be a steel pipe, a steel plate, or a steel bar. The duplex stainless steel material of the present embodiment is preferably a steel pipe. The duplex stainless steel material of the present embodiment is more preferably a seamless steel pipe.

[Uses of duplex stainless steel material of present embodiment]

[0178] The duplex stainless steel material of the present embodiment can be widely applied to uses requiring intergranular corrosion resistance. In particular, the duplex stainless steel material of the present embodiment is suitable for the steel material of urea production plants. However, the use of the duplex stainless steel material of the present embodiment is not limited to the range described above.

[Production method of duplex stainless steel material]

[0179] One example of a production method of the duplex stainless steel material of the present embodiment will be described. The below described production method of the duplex stainless steel material is one example for producing the duplex stainless steel material of the present embodiment. Therefore, the duplex stainless steel having the configuration described above may be produced by a method other than the production method described below. However, the below described production method is a preferable example of the production method of the duplex stainless steel material of the present embodiment.

[0180] One example of the production method of the duplex stainless steel material of the present embodiment includes the following steps.

- (Step 1) Starting material preparation step
- (Step 2) Hot working step
- (Step 3) Cold working step
- (Step 4) Solution treatment step

[0181] Main production conditions in the above-described step 1 to step 4 are as follows.

- (Condition 1) Reduction of area R1 in hot working step: 60% or more
- (Condition 2) Cooling rate CR1 after hot working: 50°C/sec or more (water cooling)
- (Condition 3) Reduction of area R2 in cold working step: 60% or more
- (Condition 4) FA defined by Formula (A): 150 to 500

$$FA = R1/100 \times K_{CR} \times R2/100 \times T1 \times (t1/60)^{0.5} \quad (A)$$

Where, T1 in Formula (A) is the solution treatment temperature (°C) in the solution treatment step, and t1 is a holding time (min) at a solution treatment temperature T1. Further, K_{CR} is substituted by "1.2" when the cooling rate CR1 immediately after the hot working is 50°C/sec or more (water cooling) and is substituted by "0.8" when the cooling rate CR1 immediately after the hot working is less than 50°C/sec (natural cooling).

[0182] Hereafter, each step will be described.

[(Step 1) Starting material preparation step]

[0183] In the starting material preparation step, a starting material having the chemical composition that satisfies Feature 1 is prepared. The starting material may be any of an ingot, a slab, a bloom, and a billet. When the starting material is produced, it is produced by the following method. Molten steel having the chemical composition that satisfies Feature 1 is produced. By using the produced molten steel, an ingot is produced by an ingot-making process. By using the produced molten steel, a slab, a bloom, or a billet (cylindrical starting material) may be produced by a continuous casting process. A billet may be produced by subjecting the produced ingot, slab, or bloom to hot working. For example, a billet of cylindrical shape may be produced by subjecting the ingot to hot forging, and the billet is used as the starting material (cylindrical starting material). In this case, the temperature of the starting material immediately before starting hot forging is not particularly limited, but is, for example, 1000 to 1300°C. The cooling method of the starting material after the hot forging will not be particularly limited.

[(Step 2) Hot working step]

[0184] In the hot working step, the starting material prepared in the starting material preparation step is subjected to hot working to produce an intermediate steel material. The intermediate steel material may be any of a steel pipe, a steel plate, and a steel bar.

[0185] When the intermediate material is a steel pipe, the following processing is performed in the hot working step. First, a cylindrical starting material is prepared. By machining, a through hole is formed along the central axis of the cylindrical starting material. The cylindrical starting material in which a through hole is formed is subjected to hot extrusion typified by the Ugine-Sejournet process to produce an intermediate material (seamless steel pipe). The temperature of the starting material immediately before hot extrusion is not particularly limited. The heating temperature of the starting material immediately before hot extrusion is, for example, 1000 to 1300°C.

[0186] When the intermediate material is a steel plate, the hot working step uses, for example, one or more rolling mills including a pair of work rolls. The steel plate is produced by subjecting the starting material such as a slab to hot rolling by using the rolling mill. The heating temperature of the starting material during hot rolling is, for example, 1000 to 1300°C.

[0187] When the intermediate material is a steel bar, the hot working step includes, for example, a rough rolling step and a finish rolling step. In the rough rolling step, the starting material is subjected to hot working to produce a billet. The rough rolling step uses, for example, a blooming mill. A bloom is subjected to blooming by the blooming mill to produce a billet. When a continuous rolling mill is disposed in the downstream of the blooming mill, the billet after blooming may be further subjected to hot rolling by using the continuous rolling mill to produce a billet having a smaller size. In the continuous rolling mill, for example, a horizontal stand with a pair of horizontal rolls, and a vertical stand with a pair of vertical rolls are alternately arranged in a row. The starting material temperature immediately before the rough rolling step is not particularly limited, but is, for example, 1000 to 1300°C. In the finish rolling step, firstly the billet is heated. The billet after heating is subjected to hot rolling by using the continuous rolling mill to produce a steel bar. The heating temperature in a heating furnace in the finish rolling step is not particularly limited, but is for example, 1000 to 1200°C.

[0188] The intermediate steel material immediately after the end of hot working is rapidly cooled. Specifically, the intermediate steel material immediately after the hot working is water cooled. By water cooling, the cooling rate CR1 of the intermediate material will be 50°C/sec or more. By water cooling, the intermediate steel material is allowed to cool to a normal temperature. By subjecting the intermediate steel material to water cooling, strain accumulated in the hot working step is suppressed from being released.

[0189] It is noted that the intermediate steel material after water cooling is subjected to next cold working step without being subjected to heat treatment such as an annealing treatment. This will suppress strain accumulated in the hot working step from being released.

[(Step 3) Cold working step]

[0190] In a cold working step, the intermediate steel material produced by the hot working step is subjected to cold working. When the intermediate steel material is a steel pipe or a steel bar, the cold working is cold drawing or cold Pilger rolling. When the intermediate steel material is a steel plate, the cold working is, for example, cold rolling. As a result of performing the cold working step, further strain will be accumulated in the intermediate steel material before solution treatment. Thereby, during the solution treatment, fine austenite is precipitated with the accumulated strain being as its nucleus, and as a result, ferrite with little variation in thickness in the L direction is obtained.

[0191] It is noted that before subjecting the intermediate steel material after the hot working step to the cold working, a descaling treatment may be performed. The descaling treatment may not necessarily be performed. When the descaling treatment is performed, the descaling treatment is, for example, shotblasting and/or pickling.

[(Step 4) Solution treatment step]

[0192] In a solution treatment step, the intermediate steel material after the cold working step is subjected to a solution treatment. In the solution treatment, precipitates are dissolved. In the present embodiment, in the solution treatment, ferrite having little variation in thickness in the L direction is formed due to strain accumulated in the intermediate steel material in the hot working step and the cold working step. The solution treatment temperature T1 in the solution treatment is 1000 to 1200°C. A holding time t1 at the solution treatment temperature T1 is 1.00 to 50.00 minutes.

[Condition 1 to Condition 4]

[0193] In the production steps described above, each step is performed such that the following conditions are satisfied.

(Condition 1) Reduction of area R1 in hot working step: 60% or more

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(Condition 2) Cooling rate CR1 after hot working: 50°C/sec or more (water cooling)

(Condition 3) Reduction of area R2 in cold working step: 60% or more

(Condition 4) FA defined by Formula (A): 150 to 500

$$FA = R1/100 \times K_{CR} \times R2/100 \times T1 \times (t1/60)^{0.5} \quad (A)$$

[0194] Where, T1 in Formula (A) is the solution treatment temperature (°C) in the solution treatment step, and t1 is a holding time (min) at the solution treatment temperature T1. Further, K_{CR} is substituted by "1.2" when the cooling rate CR1 immediately after the end of hot working is 50°C/sec or more (water cooling) and is substituted by "0.8" when the cooling rate CR1 immediately after the end of hot working is less than 50°C/sec (natural cooling).

[0195] Hereafter, each condition will be described.

[Condition 1]

[0196] The reduction of area R1(%) in the hot working step is defined by the following formula.

Reduction of area R1 = (1 - sectional area perpendicular to longitudinal direction of intermediate steel material after hot working/sectional area perpendicular to longitudinal direction of starting material) × 100

[0197] If the reduction of area R1 is less than 60%, strain to be accumulated in the intermediate steel material is insufficient. For that reason, the duplex stainless steel material after production cannot satisfy Feature 2. Therefore, the reduction of area R1 is 60% or more.

[Condition 2]

[0198] The cooling rate CR1 of the intermediate steel material immediately after the hot working is set to 50°C/sec or more. This cooling rate is realized by water cooling. When the intermediate steel material is air cooled, the cooling rate CR1 will be less than 50°C/sec. If the intermediate steel material immediately after the hot working is subjected to air cooling instead of water cooling, the strain accumulated in the intermediate steel material by the hot working is released during cooling. Therefore, an amount of strain for expressing the microstructure of Feature 2 in the solution treatment is insufficient. Therefore, the cooling rate CR1 is 50°C/sec or more.

[Condition 3]

[0199] The reduction of area R2(%) in the cold working step is defined by the following formula.

Reduction of area R2 = (1 - sectional area perpendicular to longitudinal direction of intermediate steel material after cold working/sectional area perpendicular to longitudinal direction of intermediate steel material before cold working) × 100

[0200] If the reduction of area R2 is less than 60%, the strain to be accumulated in the intermediate steel material is insufficient. For that reason, the duplex stainless steel material after production cannot satisfy Feature 2. Therefore, the reduction of area R2 is 60% or more.

[Condition 4]

[0201] Further, in the production steps described above, FA defined by Formula (A) is 150 to 500.

$$FA = R1/100 \times K_{CR} \times R2/100 \times T1 \times (t1/60)^{0.5} \quad (A)$$

[0202] Where, T1 in Formula (A) is the solution treatment temperature (°C) in the solution treatment step, and t1 is the holding time (min) at the solution treatment temperature T1. Further, K_{CR} is substituted by "1.2" when the cooling rate CR1 immediately after the hot working is 50°C/sec or more (water cooling) and is substituted by "0.8" when the cooling rate CR1 immediately after the hot working is less than 50°C/sec (natural cooling).

[0203] FA is a production condition for the microstructure of the duplex stainless steel material to satisfy Feature 2. Out of FA, " $R1/100 \times K_{CR} \times R2/100$ " is a factor regarding the accumulation amount of strain, and " $T1 \times (t1/60)^{0.5}$ " is a factor for

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expressing the segregation of austenite during solution treatment. If FA is 150 to 500, a sufficient amount of strain is accumulated in the intermediate steel material before solution treatment, and a condition in the solution treatment is also appropriate. Therefore, the microstructure of the duplex stainless steel material after production satisfies Feature 2.

[0204] By the production steps described so far, the duplex stainless steel material that satisfies Feature 1 and Feature 2 can be produced.

[0205] Hereafter, advantageous effects of the duplex stainless steel material of the present embodiment will be described more specifically with reference to examples. A condition in the following examples is one example condition adopted to confirm the feasibility and advantageous effects of the duplex stainless steel material of the present embodiment. Therefore, the duplex stainless steel material of the present embodiment is not limited to this one example condition.

EXAMPLES

[0206] Duplex stainless steel pipes (seamless steel pipes) having chemical compositions shown in Table 1-1 and Table 1-2 were produced.

[Table 1-1]

[0207]

TABLE1-1

Test Number	Chemical composition (unit is mass%, with the balance Fe and impurities)									
	Essential element									
	C	Si	Mn	P	S	Cr	Ni	Mo	W	N
1	0.018	0.32	0.47	0.019	0.0004	27.2	7.8	0.90	2.25	0.33
2	0.015	0.45	0.95	0.005	0.0006	27.8	8.7	1.52	2.38	0.35
3	0.012	0.22	0.64	0.012	0.0003	27.2	8.2	0.52	2.61	0.31
4	0.018	0.32	0.47	0.022	0.0002	26.8	7.5	1.12	2.25	0.33
5	0.016	0.21	0.83	0.015	0.0004	27.7	6.5	0.82	2.15	0.36
6	0.013	0.35	0.55	0.001	0.0005	27.5	7.7	0.93	2.25	0.32
7	0.027	0.38	1.23	0.007	0.0004	26.5	7.5	1.25	2.35	0.31
8	0.011	0.28	1.15	0.012	0.0003	27.5	8.3	0.35	2.85	0.34
9	0.015	0.21	0.82	0.021	0.0004	27.6	7.1	0.56	2.22	0.36
10	0.014	0.25	0.61	0.003	0.0005	27.9	7.4	1.51	2.35	0.32
11	0.018	0.31	0.52	0.002	0.0003	27.8	7.6	0.99	2.28	0.33
12	0.014	0.44	0.47	0.002	0.0006	27.1	7.5	0.91	2.18	0.35
13	0.021	0.21	1.56	0.025	0.0005	27.8	9.1	1.35	2.56	0.31
14	0.017	0.34	0.51	0.015	0.0004	27.2	7.1	0.85	2.81	0.31
15	0.016	0.38	0.56	0.026	0.0003	27.3	8.1	0.95	2.55	0.32
16	0.015	0.25	0.85	0.023	0.0007	27.8	8.2	1.30	2.25	0.35
17	0.011	0.33	0.45	0.021	0.0008	27.9	9.3	1.35	2.65	0.32
18	0.018	0.32	0.90	0.016	0.0004	27.6	7.2	0.94	2.15	0.39
19	0.015	0.24	0.85	0.021	0.0004	27.5	8.1	1.20	2.24	0.33
20	0.019	0.44	0.82	0.005	0.0005	27.3	8.3	1.20	2.56	0.33
21	0.014	0.29	0.51	0.014	0.0004	27.5	6.1	0.97	2.67	0.32

[Table 1-2]

[0208]

TABLE1-2

Test Number	Chemical composition (unit is mass%, with the balance Fe and impurities)								
	Essential element		Optional element						
	O	Al	Cu	Co	Ti	Nb	Ca	Mg	B
1	0.005	0.020	-	-	-	-	-	-	-
2	0.007	0.019	-	-	-	-	-	-	-
3	0.005	0.015	-	-	-	-	-	-	-
4	0.011	0.018	0.28	-	-	-	-	-	-
5	0.008	0.021	-	0.5	-	-	-	-	-
6	0.005	0.020	-	-	0.150	-	-	-	-
7	0.007	0.045	-	-	-	0.100	-	-	-
8	0.011	0.022	-	-	-	-	0.004	-	-
9	0.009	0.022	-	-	-	-	-	0.003	-
10	0.005	0.015	-	-	-	-	-	-	0.001
11	0.011	0.035	-	-	0.064	-	-	0.001	-
12	0.003	0.025	0.10	0.3	-	0.095	-	-	-
13	0.005	0.031	-	0.4	0.110	0.030	0.002	-	-
14	0.004	0.015	-	-	-	-	-	-	-
15	0.005	0.016	-	-	-	-	-	-	-
16	0.003	0.012	-	-	-	-	-	-	-
17	0.009	0.005	-	-	-	-	-	-	-
18	0.007	0.014	-	-	-	-	-	-	-
19	0.003	0.012	-	-	-	-	-	-	-
20	0.005	0.019	-	-	-	-	-	-	-
21	0.005	0.016	-	-	-	-	-	-	-

[0209] The symbol "-" in Table 1-2 means that the corresponding elemental content is 0% in the significant figures (numerical values up to the smallest digit) specified in the embodiments. In other words, it means that the corresponding elemental content is 0% when rounding off fractions in the significant digits (numerical values up to the smallest digit) specified in the embodiment above. For example, it means that the Cu content in test number 1 was "0" % when rounded to the third decimal place. The remainder of the elements other than those listed in Tables 1-1 and 1-2 were Fe and impurities.

[0210] Specifically, first, in the starting material preparation step, blooms having the chemical compositions shown in Table 1-1 and Table 1-2 were produced. The bloom was hot forged to produce a cylindrical starting material (round billet). The heating temperature of the bloom in the hot forging was 1100 to 1250°C. The round billet after the hot forging was allowed to cool to a normal temperature.

[0211] In the hot working step, the round billet was subjected to hot extrusion to produce a steel pipe (seamless steel pipe) which is an intermediate steel material. The heating temperature of the round billet during the hot working was 1100 to 1200°C. The reduction of area R1(%) during the hot working was as shown in Table 2.

[Table 2]

[0212]

TABLE2

Test Number	Production condition				Microstructure			Corrosion rate (g/m ² /h)	Remarks
	Hot working reduction of area R1 (%)	CR1 (°C/sec)	Cold working reduction of area R2 (%)	FA	Ferrite average thickness TF (μm)	Sample standard deviation ΔTF (μm)	Austenite average thickness TA (μm)		
1	90	≥50	80	461	2.78	0.25	3.08	0.088	Inventive example
2	90	≥50	80	262	3.52	0.34	3.79	0.094	Inventive example
3	95	≥50	80	348	3.13	0.35	3.83	0.089	Inventive example
4	95	≥50	80	159	4.27	0.48	4.41	0.094	Inventive example
5	80	≥50	85	210	3.92	0.34	3.59	0.086	Inventive example
6	80	≥50	85	201	3.84	0.22	3.48	0.075	Inventive example
7	85	≥50	85	213	3.88	0.42	4.28	0.081	Inventive example
8	65	≥50	90	330	3.48	0.35	3.78	0.091	Inventive example
9	85	≥50	90	326	3.73	0.32	3.89	0.089	Inventive example
10	90	≥50	85	226	3.72	0.32	3.81	0.096	Inventive example
11	75	≥50	85	243	3.39	0.33	3.64	0.088	Inventive example
12	80	≥50	80	197	4.01	0.34	4.19	0.087	Inventive example
13	98	≥50	65	188	3.79	0.35	4.14	0.089	Inventive example
14	58	≥50	80	128	5.53	1.15	5.71	0.103	Comparative example
15	80	<50	65	98	6.92	1.17	5.36	0.123	Comparative example
16	75	≥50	55	111	7.62	0.56	4.78	0.111	Comparative example
17	70	≥50	65	122	6.78	0.87	5.21	0.114	Comparative example
18	65	≥50	65	102	7.19	1.26	6.53	0.121	Comparative example
19	70	≥50	70	145	4.21	0.66	4.48	0.105	Comparative example
20	95	≥50	90	834	2.09	0.35	6.81	0.111	Comparative example

(continued)

Test Number	Production condition				Microstructure			Corrosion rate (g/m ² /h)	Remarks
	Hot working reduction of area R1 (%)	CR1 (°C/sec)	Cold working reduction of area R2 (%)	FA	Ferrite average thickness TF (μm)	Sample standard deviation ΔTF (μm)	Austenite average thickness TA (μm)		
21	90	≥50	95	590	2.28	0.24	5.22	0.115	Comparative example

[0213] The intermediate steel material immediately after the hot working was cooled to normal temperature. The cooling rate CR1 (°C/sec) was as shown in Table 2. The intermediate steel material after cooling was subjected to cold working without being subjected to an annealing treatment or the like. Specifically, the intermediate steel material was subjected to cold working by using a Pilger rolling mill. The reduction of area R2(%) in cold working was as shown in Table 2.

[0214] The intermediate steel material after the cold working step was subjected to the solution treatment step. In the solution treatment step, the solution treatment temperature T1 was 1000 to 1200°C, and the holding time t1 at the solution treatment temperature T1 was 1.00 to 50.00 minutes. It is noted that the FA value of each test number was as shown in Table 2.

[0215] Through the production steps described above, duplex stainless steel materials (seamless steel pipes) were produced.

[Evaluation test]

[0216] The produced duplex stainless steel material of each test number was subjected to the following evaluation tests.

(Test 1) Ferrite area fraction measurement test

(Test 2) Ferrite average thickness TF, sample standard deviation ΔTF, and austenite average thickness TA measurement tests

(Test 3) Intergranular corrosion resistance evaluation test when formed into a welded joint

[0217] Hereafter, Test 1 to Test 3 will be described.

[(Test 1) Ferrite area fraction measurement test]

[0218] Based on the method described in [Ferrite area fraction measurement method] described above, the ferrite area fraction of the duplex stainless steel material having each test number was determined. As a result, in any test number, the microstructure was composed of ferrite and austenite, and the ferrite area fraction was 35 to 55%.

[(Test 2) Ferrite average thickness TF, sample standard deviation ΔTF, and austenite average thickness TA measurement tests]

[0219] Based on [Measurement method of Ferrite average thickness TF, sample standard deviation ΔTF of ferrite thickness, and austenite average thickness TA] described above, the ferrite average thickness TF, the sample standard deviation ΔTF, and the austenite average thickness TA of the duplex stainless steel material of each test number were determined. Determined results are shown in Table 2.

[(Test 3) Intergranular corrosion resistance evaluation test when formed into welded joint]

[0220] By the method described in [Intergranular corrosion resistance evaluation method] described above, a welded joint of the duplex stainless steel material of each test number was produced. Then, by the method described in [Intergranular corrosion resistance evaluation method] described above, a nitric acid corrosion test of ASTM A262 Practice C was performed using a test specimen collected from the welded joint to determine the corrosion rate (g/m²/h). Determined corrosion rates are shown in Table 2.

[Evaluation results]

[0221] Referring to Table 1-1, Table 1-2 and Table 2, the duplex stainless steel material of Test Numbers 1 to 13 satisfied Feature 1 and Feature 2. Therefore, in the duplex stainless steel material having these test numbers, the corrosion rate when formed into the welded joint was 0.100 g/m²/h or less, and thus, sufficient intergranular corrosion resistance was obtained.

[0222] On the other hand, in Test Number 14, the reduction of area R1 in the hot working step was less than 60%. Therefore, the duplex stainless steel material did not satisfy Feature 2. As a result, the corrosion rate when formed into the welded joint was more than 0.100 g/m²/h, and thus, sufficient intergranular corrosion resistance was not obtained.

[0223] In Test Number 15, the cooling rate CR1 after the hot working was less than 50°C/sec. Therefore, the FA value was less than 150. For that reason, the duplex stainless steel material did not satisfy Feature 2. As a result, the corrosion rate when formed into the welded joint was more than 0.100 g/m²/h, and thus, sufficient intergranular corrosion resistance was not obtained.

[0224] In Test Number 16, the reduction of area R2 in the cold working step was less than 60%. For that reason, the duplex stainless steel material did not satisfy Feature 2. As a result, the corrosion rate when formed into the welded joint was more than 0.100 g/m²/h, and thus, sufficient intergranular corrosion resistance was not obtained.

[0225] In Test Numbers 17 to 19, although the reduction of area R1, the cooling rate CR1, and the reduction of area R2 were appropriate, the FA value was less than 150. For that reason, the duplex stainless steel materials did not satisfy Feature 2. As a result, the corrosion rate when formed into the welded joint was more than 0.100 g/m²/h, and thus, sufficient intergranular corrosion resistance was not obtained.

[0226] In Test Numbers 20 and 21, although the reduction of area R1, the cooling rate CR1, and the reduction of area R2 were appropriate, the FA value was more than 500. For that reason, the duplex stainless steel materials did not satisfy Feature 2. As a result, the corrosion rate when formed into the welded joint was more than 0.100 g/m²/h, and thus, sufficient intergranular corrosion resistance was not obtained.

[0227] So far, the embodiment of the present disclosure has been described. However, the embodiment described above is only an example for implementing the present disclosure. Therefore, the present disclosure can be implemented, without being limited to the embodiment described above, by appropriately changing the embodiment described above within the range not departing from the concept thereof.

Claims

1. A duplex stainless steel material, comprising:

a chemical composition consisting of: in mass%,

C: 0.030% or less,

Si: 0.50% or less,

Mn: 2.00% or less,

P: 0.040% or less,

S: 0.0010% or less,

Cr: 26.0 to 28.0%,

Ni: 6.0 to 10.0%,

Mo: 0.20 to 1.70%,

W: more than 2.00 to 3.00%,

N: more than 0.30 to 0.40%,

O: 0.020% or less,

Al: 0.050% or less,

Cu: 0 to 0.30%,

Co: 0 to 1.0%,

Ti: 0 to 0.300%,

Nb: 0 to 0.300%,

Ca: 0 to 0.010%,

Mg: 0 to 0.010%, and

B: 0 to 0.010%,

with the balance being Fe and impurities; wherein

with a longitudinal direction of the duplex stainless steel material being defined as an L direction, and a thickness

direction of the duplex stainless steel material being defined as a T direction,
 when, in a section including the L direction and the T direction of the duplex stainless steel material, three
 rectangular regions are identified at a pitch of 100 mm in the L direction, where each identified region is a rectangle
 of 200 μm in the L direction and 200 μm in the T direction, and
 when, in each rectangular region,
 five line segments, which extend in the T direction and are arranged at equal intervals in the L direction of the
 rectangular region, thereby dividing the rectangular region into six equal parts in the L direction, are defined as line
 segments LS,
 a ferrite average thickness TF of each ferrite overlapping the 15 line segments LS of the three rectangular regions
 is 2.50 to 4.50 μm , and a sample standard deviation ΔTF of ferrite thickness is 0.50 μm or less, and
 an austenite average thickness TA of each austenite overlapping the 15 line segments LS is 2.50 to 4.50 μm .

2. The duplex stainless steel material according to claim 1, wherein
 the chemical composition contains one or more elements selected from the group consisting of:

Cu: 0.01 to 0.30%,
 Co: 0.1 to 1.0%,
 Ti: 0.001 to 0.300%,
 Nb: 0.001 to 0.300%,
 Ca: 0.001 to 0.010%,
 Mg: 0.001 to 0.010%, and
 B: 0.001 to 0.010%.

3. The duplex stainless steel material according to claim 1 or claim 2, wherein the duplex stainless steel material is a
 seamless steel pipe.

FIG.1

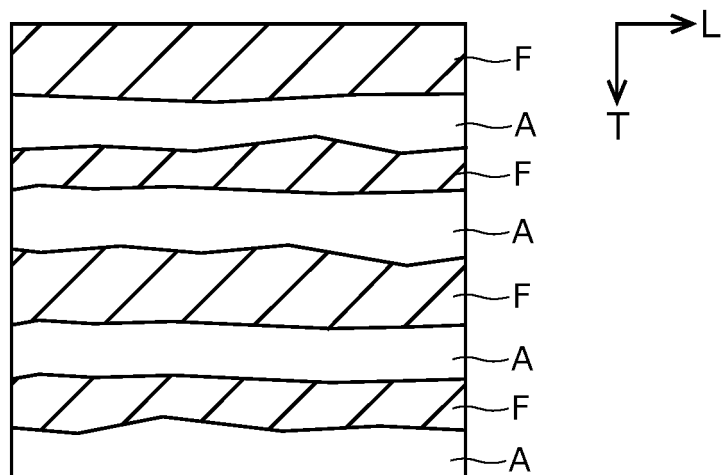


FIG.2

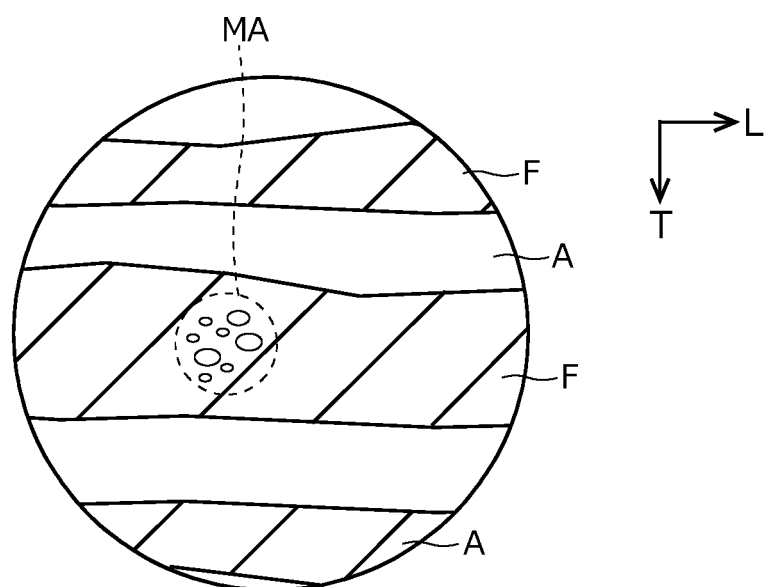


FIG.3

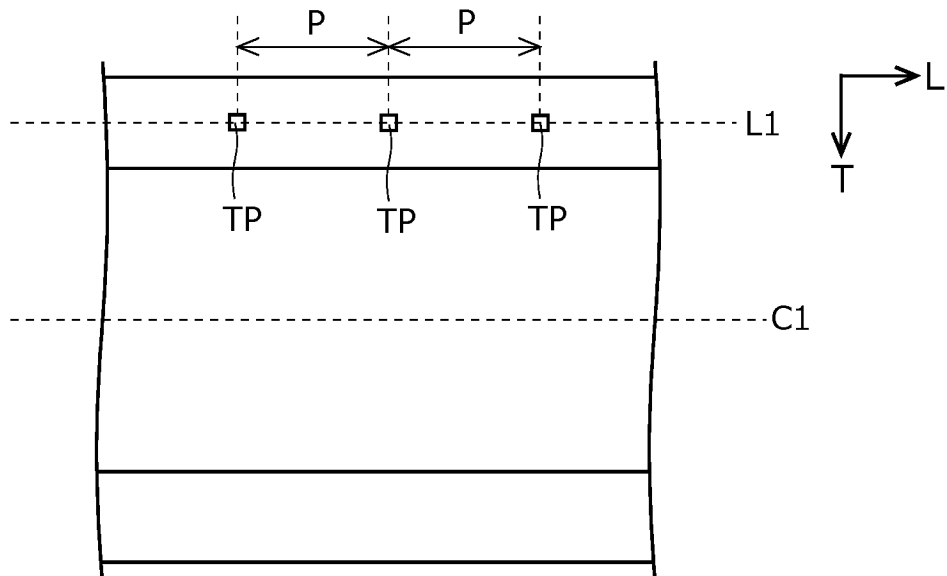


FIG.4

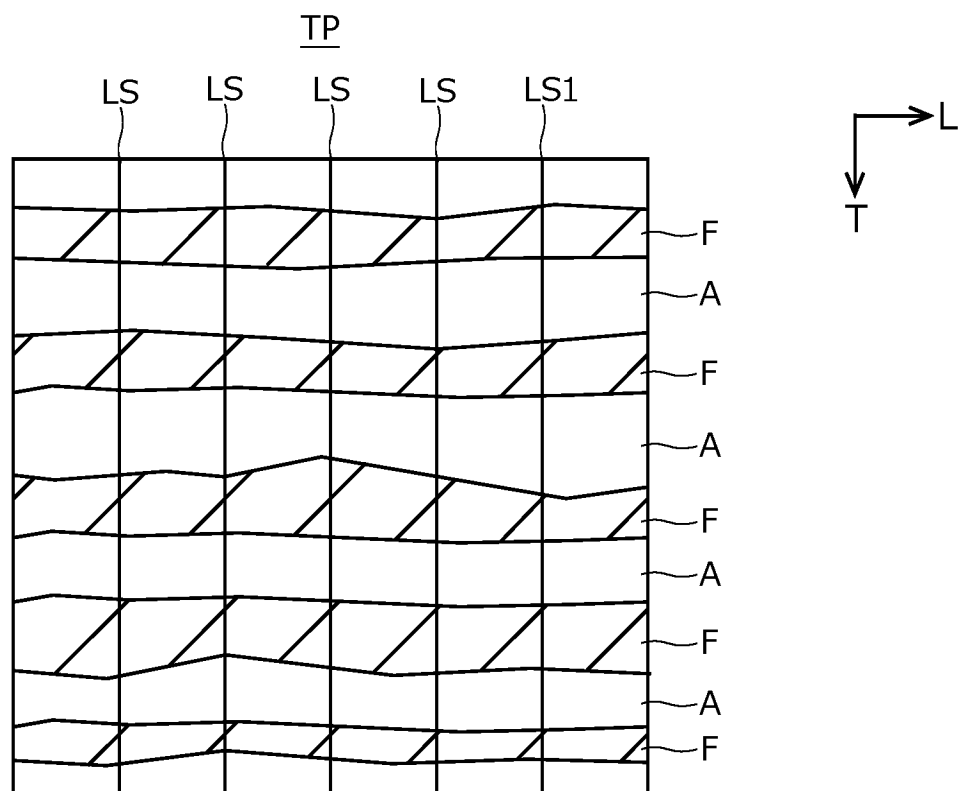
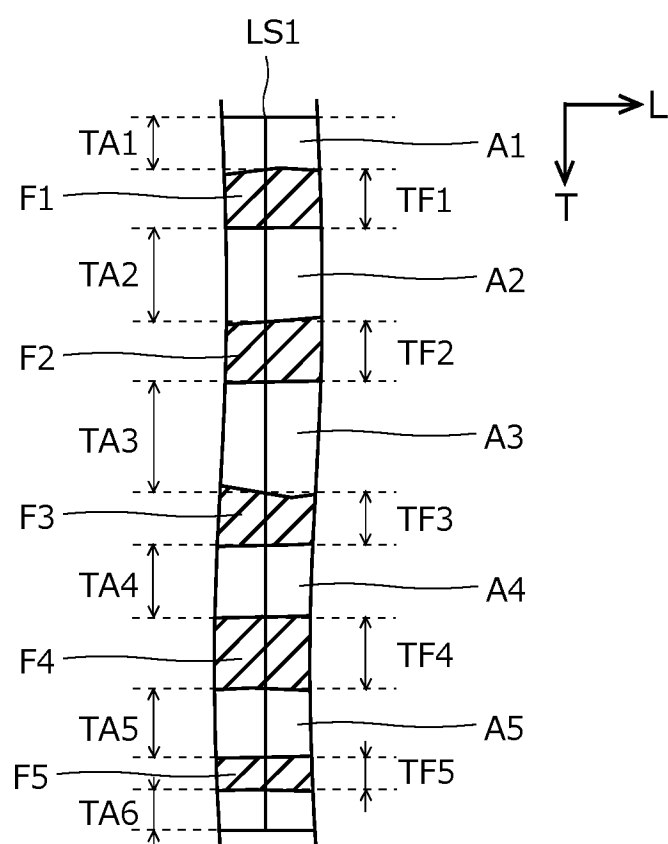


FIG.5



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2023/030249

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/00(2006.01)i; *C21D 8/00*(2006.01)i; *C21D 9/08*(2006.01)i; *C22C 38/58*(2006.01)i
FI: C22C38/00 302H; C22C38/58; C21D8/00 E; C21D9/08 E

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)

C22C38/00; C21D8/00; C21D9/08; C22C38/58

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	JP 2011-127186 A (SUMITOMO METAL IND LTD) 30 June 2011 (2011-06-30) paragraphs [0001], [0047]-[0049], table 1	1-3
A	JP 2007-146202 A (SUMITOMO METAL IND LTD) 14 June 2007 (2007-06-14)	1-3
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A	WO 2020/218426 A1 (NIPPON STEEL CORP) 29 October 2020 (2020-10-29)	1-3

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

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/JP2023/030249

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