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(54) **AUSTENITIC STAINLESS STEEL WITH IMPROVED STRENGTH AND LOW-TEMPERATURE IMPACT TOUGHNESS, AND MANUFACTURING METHOD THEREFOR**

(57) According to the present disclosure, an austenitic stainless steel comprising, in percent by weight (wt%), 0.10% or less of C (excluding 0), 1.50% or less of Si (excluding 0), 16 to 23% of Cr, 5.1 to 12% of Ni, 15% or less of Mn (excluding 0), 1.2% or less of Cu (excluding 0), 0.1 to 0.4% of N, 0.01% or less of (Nb+V), 1.5% or less of Mo, and the remainder of Fe and inevitable impurities, wherein a product of a strength index represented by Formula (1) below and a Stacking Fault Energy (SFE) represented by Formula (2) below is 0 or more, can be provided.

Strength Index: (Yield Strength (MPa)) - 0.9Cr + 2Ni - 12Si - 1.1Mn - 80N + 400C - 275

Formula (1)

Formula (2) SFE: 25.7 + 2Ni + 410C - 0.9Cr - 77N - 13Si - 1.2Mn

(In Formula (1) and Formula (2), Cr, Ni, Si, Mn, N, and C mean the content (wt%) of each element)

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Description

[Technical Field]

- 5 **[0001]** The present disclosure relates to an austenitic stainless steel with improved yield strength (MPa) and low-temperature impact toughness, and a manufacturing method therefor.

[Background Art]

- 10 **[0002]** Recently, as the development and distribution of hydrogen fuel vehicles expand, the demand for storage containers and parts required for hydrogen storage and transportation is increasing. Gaseous hydrogen is cooled to a temperature of -40 to -60°C and stored in a storage tank in consideration of a gas temperature rise during filling, and liquid hydrogen is stored at -253°C. Therefore, steel materials for hydrogen storage containers and parts are required to prevent degradation of strength and toughness due to hydrogen and cryogenic temperatures in the entire temperature range from -253°C to room temperature.

- 15 **[0003]** Generally, an austenite structure is known to be advantageous for low-temperature toughness compared to a martensite structure or a ferrite structure, and thus is used as a steel material for hydrogen storage containers and parts. Representative austenitic stainless steels used as steel materials for hydrogen storage containers and parts are 300-series stainless steels, and 304L and 316L are mainly used. However, such commercial stainless steels have relatively low strength, so there is a disadvantage that the thickness of the material increases when applied to a cryogenic environment.

- 20 **[0004]** In addition, physical properties such as impact toughness of the austenitic stainless steel may deteriorate as the temperature decreases, and exposure to a hydrogen environment causes hydrogen to charge into the steel material, potentially degrading physical properties. Therefore, there is a need for the development of an austenitic stainless steel having excellent strength and toughness even in a cryogenic hydrogen use environment by simultaneously considering the degradation of physical properties of the steel material due to temperature and the degradation of physical properties of the steel material due to hydrogen.

[Disclosure]

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[Technical Problem]

- [0005]** The present disclosure is intended to provide an austenitic stainless steel having excellent low-temperature impact toughness and excellent yield strength even in an environment where the use environment is cryogenic, such as liquid hydrogen storage, and a manufacturing method therefor.

- 35 **[0006]** The problems to be solved by the present disclosure are not limited to the problems mentioned above, and other problems not mentioned will be clearly understood by those skilled in the art from the following description.

[Technical Solution]

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- [0007]** An aspect of the present disclosure relates to an austenitic stainless steel comprising, in percent by weight (wt%), 0.10% or less of C (excluding 0), 1.50% or less of Si (excluding 0), 16 to 23% of Cr, 5.1 to 12% of Ni, 15% or less of Mn (excluding 0), 1.2% or less of Cu (excluding 0), 0.1 to 0.4% of N, 0.01% or less of (Nb+V), and the remainder of Fe and inevitable impurities, wherein a product of a strength index represented by Formula (1) below and a Stacking Fault Energy (SFE) represented by Formula (2) below is 0 or more.

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Strength Index: (Yield Strength (MPa)) - 0.9Cr + 2Ni - 12Si - 1.1Mn - 80N + 400C - 275

Formula (1)

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Formula (2) SFE: $25.7 + 2\text{Ni} + 410\text{C} - 0.9\text{Cr} - 77\text{N} - 13\text{Si} - 1.2\text{Mn}$ **[0008]** (In Formula (1) and Formula (2), Cr, Ni, Si, Mn, N, and C mean the content (wt%) of each element)

- 55 **[0009]** The austenitic stainless steel according to an aspect of the present disclosure may further include 1.5% or less of Mo (excluding 0).

[0010] In the austenitic stainless steel according to an aspect of the present disclosure, the value of Formula (1) may be 0 to 100.**[0011]** In the austenitic stainless steel according to an aspect of the present disclosure, the value of Formula (2) may

be 0 to 40.

[0012] In the austenitic stainless steel according to an aspect of the present disclosure, the value of Formula (3) below may be 0 or more.

$$\text{Formula (3): } (100N) + \text{Mn} - \text{Ni}$$

(wherein N, Mn, and Ni mean the content (wt%) of each element)

[0013] In the austenitic stainless steel according to an aspect of the present disclosure, the value of Formula (4) below may be 0 or more.

$$\text{Formula (4): } (\text{Ni} + 0.52\text{Cu} + 40(\text{C} + \text{N}) + 0.7\text{Mn} + 45) - (0.48(\text{Cr} + \text{Mo} + 1.7\text{Si})) - 51$$

(wherein Ni, Cu, C, N, Mn, Cr, Mo, and Si mean the content (wt%) of each element)

[0014] In the austenitic stainless steel according to an aspect of the present disclosure, a content of delta ferrite may be 4% or less by area fraction.

[0015] The austenitic stainless steel according to an aspect of the present disclosure may have a yield strength of 280 MPa or more.

[0016] The austenitic stainless steel according to an aspect of the present disclosure may have a Charpy impact energy of 73 J or more at -196°C.

[0017] The austenitic stainless steel according to an aspect of the present disclosure may have a Charpy impact energy of 54 J or more at -253°C.

[0018] A method for manufacturing an austenitic stainless steel according to an aspect of the present disclosure includes: preparing a slab comprising, in percent by weight (wt%), 0.10% or less of C (excluding 0), 1.50% or less of Si (excluding 0), 16 to 23% of Cr, 5.1 to 12% of Ni, 15% or less of Mn (excluding 0), 1.2% or less of Cu (excluding 0), 0.1 to 0.4% of N, 0.01% or less of (Nb+V), and the remainder of Fe and inevitable impurities, wherein a product of a strength index represented by Formula (1) below and a Stacking Fault Energy (SFE) represented by Formula (2) below is 0 or more; hot rolling the slab at a temperature of 1050 to 1300°C to manufacture a hot-rolled steel sheet; and annealing the hot-rolled steel sheet at a temperature of 900 to 1,200°C.

$$\text{Strength Index: (Yield Strength (MPa)) - 0.9Cr + 2Ni - 12Si - 1.1Mn - 80N + 400C - 275} \quad \text{Formula (1)}$$

$$\text{Formula (2) SFE: } 25.7 + 2\text{Ni} + 410\text{C} - 0.9\text{Cr} - 77\text{N} - 13\text{Si} - 1.2\text{Mn}$$

[0019] (In Formula (1) and Formula (2), Cr, Ni, Si, Mn, N, and C mean the content (wt%) of each element)

[0020] The method for manufacturing an austenitic stainless steel according to an aspect of the present disclosure may further include 1.5% or less of Mo (excluding 0).

[0021] In the method for manufacturing an austenitic stainless steel according to an aspect of the present disclosure, the Formula (1) may be 0 to 100.

[0022] In the method for manufacturing an austenitic stainless steel according to an aspect of the present disclosure, the Formula (2) may be 0 to 40.

[0023] In the method for manufacturing an austenitic stainless steel according to an aspect of the present disclosure, Formula (3) below may be 0 or more.

$$\text{Formula (3): } (100N) + \text{Mn} - \text{Ni}$$

(wherein N, Mn, and Ni mean the content (wt%) of each element)

[0024] In the method for manufacturing an austenitic stainless steel according to an aspect of the present disclosure, Formula (4) below may be 0 or more.

$$\text{Formula (4): } (\text{Ni} + 0.52\text{Cu} + 40(\text{C} + \text{N}) + 0.7\text{Mn} + 45) - (0.48(\text{Cr} + \text{Mo} + 1.7\text{Si})) - 51$$

(wherein Ni, Cu, C, N, Mn, Cr, Mo, and Si mean the content (wt%) of each element)

[0025] In the method for manufacturing an austenitic stainless steel according to an aspect of the present disclosure, a hot rolling time in the manufacturing of the hot-rolled steel sheet may be 1 hour to 3 hours, and an annealing time in

the annealing may be 5 minutes to 100 minutes.

[Advantageous Effects]

[0026] According to the present disclosure, an austenitic stainless steel in which degradation of physical properties of a steel material due to hydrogen is minimized even in a cryogenic environment, and a manufacturing method therefor can be provided.

[0027] According to the present disclosure, an austenitic stainless steel having excellent yield strength and low-temperature impact toughness even in a cryogenic environment, and a manufacturing method therefor can be provided.

[0028] According to the present disclosure, as an austenitic stainless steel with improved strength and a manufacturing method therefor are provided, the amount of material used for a hydrogen storage tank can be reduced, thereby providing effects of reducing the manufacturing cost and weight of the hydrogen storage tank.

[0029] The effects obtainable in the present disclosure are not limited to the effects mentioned above, and other effects not mentioned will be clearly understood by those skilled in the art to which the present disclosure belongs from the following description.

[Modes of the Invention]

[0030] Hereinafter, preferred embodiments of the present disclosure will be described. However, embodiments of the present disclosure may be modified into various other forms, and the technical spirit of the present disclosure is not limited to the embodiments described below. In addition, the embodiments of the present disclosure are provided to more completely explain the present disclosure to those with average knowledge in the art.

[0031] The terms used in this application are merely used to describe specific examples. Therefore, for example, singular expressions include plural expressions unless the context clearly implies that they must be singular. In addition, it should be noted that terms such as "comprise" or "include" used in this application are used to clearly indicate the presence of features, steps, functions, components, or combinations thereof described in the specification, and are not used to preliminarily exclude the presence of other features, steps, functions, components, or combinations thereof.

[0032] Meanwhile, unless otherwise defined, all terms used in this specification should be viewed as having the same meaning as generally understood by those skilled in the art to which the present disclosure belongs. Therefore, unless clearly defined in this specification, specific terms should not be interpreted in an excessively ideal or formal sense.

[0033] In addition, "about", "substantially", etc. in this specification are used in the sense of being at or close to the numerical value when manufacturing and material tolerances inherent in the stated meaning are presented, and are used to prevent unscrupulous infringers from unfairly using the content of the invention in which accurate or absolute numerical values are mentioned to help the understanding of the present disclosure.

[0034] Unless specifically stated otherwise in this specification, % indicating the content of each element is based on weight.

[0035] The austenitic stainless steel according to an aspect of the present disclosure includes, in percent by weight (wt%), 0.10% or less of C (excluding 0), 1.50% or less of Si (excluding 0), 16 to 23% of Cr, 5.1 to 12% of Ni, 15% or less of Mn (excluding 0), 1.2% or less of Cu (excluding 0), 0.1 to 0.4% of N, 0.01% or less of (Nb+V), 1.5% or less of Mo, and the remainder of Fe and inevitable impurities.

[0036] Hereinafter, the role of each alloying element included in the austenitic stainless steel according to the present disclosure and its content will be described.

[0037] The content of C is 0.10% or less (excluding 0).

[0038] C is a low-cost austenite stabilizing element, which effectively suppresses the formation of delta (δ) ferrite and promotes solid solution strengthening of the steel to improve the strength of the product. Therefore, it needs to be essentially contained in the steel. A content of C exceeding 0.10% facilitates the formation of carbides with elements such as Cr, Ti, and Nb, which may degrade corrosion resistance, ductility, and toughness in the steel, so the content thereof is controlled to 0.10% or less (excluding 0), preferably 0.02 to 0.05%, and more preferably 0.02 to 0.03%.

[0039] The content of Si is 1.50% or less (excluding 0).

[0040] Si is an element used for deoxidation of steel and is an element effective for improving corrosion resistance. In addition, since Si is an element effective for solid solution strengthening and is advantageous for securing excellent strength of steel, it needs to be essentially contained in the steel. However, since Si is a ferrite stabilizing element, a Si content exceeding 1.50% may form intermetallic compounds such as sigma phase to reduce the ductility and toughness of the steel, so the content of Si is controlled to 1.50% or less, preferably 0.2 to 1.50%, and more preferably 0.38 to 0.43%.

[0041] The content of Cr is 16 to 23%.

[0042] Cr is an element that must be added to improve the corrosion resistance of stainless steel. In addition, it plays a role of solid solution strengthening by increasing the solid solubility of N in the steel. A Cr content of less than 16% fails to obtain the above-mentioned effects. However, since Cr may act as a ferrite forming element, a Cr content exceeding 23% causes excessive delta ferrite to remain, deteriorating the hot workability of the steel, and results in an unstable austenite phase. In this case, since a large amount of Ni, which is an expensive austenite phase stabilizing element, is contained to stabilize the austenite phase in the steel, it causes an increase in manufacturing cost. Therefore, the content of Cr is controlled to 16 to 23%, preferably 16.1 to 22%, and more preferably 16.1 to 21.6%.

[0043] The content of Ni is 5.1 to 12%.

[0044] Ni is an element that suppresses the formation of delta ferrite to stabilize the austenite phase and plays a role in improving low-temperature impact toughness through grain refinement. In order to obtain the above-mentioned effects, Ni must be added in an amount of 5.1% or more. However, addition of 12% or more of Ni increases the probability of surface defects, and causes an excessive increase in manufacturing cost due to the inclusion of a large amount of Ni, which is an expensive element, so the upper limit is controlled to 12%. Therefore, the content of Ni is controlled to 5.1 to 12%, preferably 5.1 to 11%, and more preferably 5.1 to 10.5%.

[0045] The content of Mn is 15% or less (excluding 0).

[0046] Mn acts as a powerful austenite phase stabilizing element together with Ni. Mn is a cheaper element than Ni and is an element that can replace expensive Ni. In addition, since it plays a role of improving low-temperature impact toughness by suppressing deformation-induced martensite transformation, it needs to be essentially included in the steel. However, excessive addition of only Mn without appropriate addition of Ni reduces the Stacking Fault Energy (SFE), which may rather degrade low-temperature impact toughness, so the addition amounts of Mn and Ni must be added in an appropriate ratio. Therefore, the upper limit of Mn is controlled to 15%, preferably 13.2% or less (excluding 0), preferably 0.4 to 13.2%, and more preferably 0.8 to 13.2%.

[0047] The content of Cu is 1.2% or less (excluding 0).

[0048] Since Cu suppresses the occurrence of martensite phase during forming and is a useful element for stabilizing the austenite phase, it needs to be essentially included in the steel. However, a Cu content exceeding 1.2% leads to significant degradation of hot workability due to the formation of a phase with a low melting point, which may cause surface defects during manufacturing, so the upper limit is controlled to 1.2%. Preferably, it is controlled to 0.1 to 1.2%, and more preferably, it is controlled to 0.36 to 1.17%.

[0049] The content of N is 0.1 to 0.4%.

[0050] N stabilizes the austenite phase and acts as an interstitial element, contributing to strength improvement by solid solution strengthening. Addition of N in an amount of 0.1% or more can improve the strength of the steel by solid solution of N, and minimize the degradation of low-temperature impact toughness, so that an austenitic stainless steel excellent in both strength and low-temperature impact toughness can be provided. However, addition of N in excess of 0.4% causes a decrease in ductility and may cause surface defects in the manufacturing process, so the content of N is controlled to 0.1 to 0.4%, and preferably controlled to 0.11 to 0.2%.

[0051] The sum of Nb and V content, Nb+V, is 0.01% or less.

[0052] Generally, Nb and V are elements helpful for strength improvement by forming precipitates. However, the precipitation strengthening method by precipitates causes a noticeable decrease in low-temperature impact toughness in a cryogenic environment, which can act as a major cause of reducing low-temperature impact toughness. In the present disclosure, high strength and cryogenic impact toughness are intended to be simultaneously implemented through solid solution strengthening and optimization of metallurgical factors, rather than the conventional precipitation strengthening method by Nb and V. Therefore, control is performed so that precipitates by Nb and V do not substantially occur. However, since Nb and V are included in the steel as inevitable impurities, the upper limit thereof is controlled to 0.01% or less.

[0053] The austenitic stainless steel according to an aspect of the present disclosure may further include 1.5% or less of Mo.

[0054] The content of Mo may be 1.5% or less.

[0055] Mo is an element effective for improving corrosion resistance in stainless steel. However, in the case of a large amount addition, low-temperature impact toughness may decrease due to an increase in the ferrite fraction, and the manufacturing cost may increase as the content of Mo, which is an expensive element, increases. Considering this, Mo may be controlled to 1.5% or less, preferably 0.4 to 1.0% or less, and more preferably 0.4 to 0.8% or less.

[0056] Other than the above composition, the remaining component is iron (Fe). However, since unintended impurities from raw materials or the surrounding environment may inevitably be mixed in during a typical manufacturing process, this cannot be excluded. Since these impurities are known to anyone skilled in the ordinary manufacturing process, all details thereof are not specifically mentioned in this specification.

[0057] Austenitic stainless steels known to be advantageous in cryogenic environments such as liquid hydrogen have low strength despite relatively excellent low-temperature impact toughness. Accordingly, use of austenitic stain-

less steel to manufacture a cryogenic tank or structure causes a disadvantage that the thickness of the steel material increases.

[0058] Accordingly, in order to implement high strength of the steel material, a strength improvement method by cold working or a precipitation strengthening method by precipitates has been proposed. In the strength improvement method by cold working, since a martensite structure appears in the manufacturing process, there is a problem that hydrogen embrittlement occurs or low-temperature impact toughness decreases even if the strength is improved. In addition, the precipitation strengthening method by precipitates was not suitable for a cryogenic hydrogen environment because the degradation of low-temperature impact toughness appeared noticeably in a cryogenic environment.

[0059] The inventors of the present disclosure researched a method for obtaining stainless steel having both high strength and excellent low-temperature impact toughness. As a result, it was found that in order to secure high strength, optimal components should be derived by identifying the correlation between yield strength and alloy composition, and in order to secure excellent low-temperature impact toughness, the Stacking Fault Energy (SFE) should be derived through the correlation between alloy compositions and optimized.

[0060] Based on this, the inventors of the present disclosure optimized the correlation between yield strength and alloy composition to improve strength within the above-mentioned alloy composition, and derived a strength index defined by Formula (1) below.

Strength Index: (Yield Strength (MPa)) - 0.9Cr + 2Ni - 12Si - 1.1Mn - 80N + 400C - 275 Formula (1)

[0061] (In Formula (1), each element symbol means the content (wt%) of each element)

[0062] A Formula (1) value of 0 or more can secure high strength characteristics of room temperature yield strength of 280 MPa or more. An excessively high derivation of the value of Formula (1) means that the content of C is excessively high, and carbides precipitate in the steel, which may degrade low-temperature impact toughness due to precipitation strengthening. Therefore, the value of Formula (1) is controlled to 0 or more. The value of Formula (1) is preferably controlled to 0 to 100, and more preferably controlled to 0 to 74.

[0063] The inventors of the present disclosure derived the Stacking Fault Energy (SFE) defined by Formula (2) through the correlation between alloy compositions to improve low-temperature impact toughness within the above-mentioned alloy composition.

Formula (2) SFE: $25.7 + 2\text{Ni} + 410\text{C} - 0.9\text{Cr} - 77\text{N} - 13\text{Si} - 1.2\text{Mn}$

[0064] (In Formula (2), each element symbol means the content (wt%) of each element)

[0065] A Formula (2) value of 0 or more results in the Charpy impact energy at -196°C appearing as 73 J or more, so excellent low-temperature impact toughness characteristics can be secured. An excessively high derivation of the value of Formula (2) facilitates the occurrence of surface defects in the manufacturing process, which may degrade the quality of the product. In addition, since it contains a large amount of expensive elements, it causes an increase in manufacturing cost, which may reduce productivity. Considering this, the value of Formula (2) is controlled to 0 or more. The value of Formula (2) is preferably 0 to 40, and more preferably 0 to 23 or less.

[0066] The inventors of the present disclosure found that the strength level of the steel material and the possibility of use in a cryogenic environment can be predicted according to Formula (1) * Formula (2). Specifically, by controlling the product of Formula (1) and Formula (2) to 0 or more, an austenitic stainless steel having a Charpy impact energy of 73 J or more at -196°C and a room temperature yield strength of 280 MPa or more was secured. A Formula (1) * Formula (2) value of 0 or less means that one of the two factors has a negative value, so low-temperature impact toughness and high strength cannot be secured simultaneously. However, an excessive value of Formula (1) * Formula (2) means that Ni, N, etc. are added excessively, so there may be problems of cost increase and degradation of low-temperature impact toughness. Considering this, the value of Formula (1) * Formula (2) is controlled to 0 or more, preferably 0 to 10,000, and more preferably 20 to 1,000.

[0067] Meanwhile, among the above-mentioned alloy compositions, Ni, Mn, and N are elements closely related to austenite phase stabilization. These elements are added to the steel to play a role in stabilizing the austenite phase, but excessive addition causes surface defects in the manufacturing process and degrades the quality of the product. In particular, excessive addition of N significantly reduces low-temperature impact toughness, and excessive addition of Mn generates Mn fumes, which may reduce productivity. Considering the correlation between these respective elements, Formula (3) below was derived.

Formula (3): $(100\text{N}) + \text{Mn} - \text{Ni}$

[0068] (In Formula (3), each element symbol means the content (wt%) of each element)

[0069] A Formula (3) value of 0 or more can secure an austenitic stainless steel having a Charpy impact energy of 73 J or more at -196°C and a room temperature yield strength of 280 MPa or more. However, an excessive derivation of the value of Formula (3) may lead to degradation of low-temperature impact toughness due to martensite transformation. Considering this, the value of Formula (3) can be controlled to 0 or more, preferably 0 to 40, and more preferably 0 to 21.

[0070] In addition, the inventors of the present disclosure derived Formula (4) below by optimizing the correlation of alloy composition related to strength based on the theoretical calculation formula of delta ferrite.

$$\text{Formula (4): } (\text{Ni} + 0.52\text{Cu} + 40(\text{C} + \text{N}) + 0.7\text{Mn} + 45) - (0.48(\text{Cr} + \text{Mo} + 1.7\text{Si})) - 51$$

[0071] (In Formula (4), each element symbol means the content (wt%) of each element)

[0072] A Formula (4) value of 0 or more can secure room temperature yield strength of 280 MPa or more. However, an excessive derivation of the value of Formula (4) causes a difficulty in securing low-temperature impact toughness. Considering this, Formula (4) can be controlled to 0 or more, preferably 0 or more and 30 or less, and more preferably 0 or more and 8 or less.

[0073] The austenitic stainless steel according to an embodiment of the present disclosure may be manufactured through a general manufacturing process of austenitic stainless steel.

[0074] In the austenitic stainless steel according to an embodiment of the present disclosure, the delta ferrite content may be 4% or less by area fraction. A delta ferrite content exceeding 4% by area fraction results in low austenite phase stability, failing to achieve high strength and excellent low-temperature impact toughness.

[0075] In the austenitic stainless steel according to an embodiment of the present disclosure, the yield strength may be 280 MPa or more. The upper limit is not limited, but may be, for example, 800 MPa or less, 600 MPa or less, or 450 MPa or less. Within the above range, strength can be further improved while low-temperature impact toughness is excellent. In this case, for example, while implementing processability suitable for use in liquefied gas storage containers, etc., excellent low-temperature impact toughness and high strength can be implemented.

[0076] In the austenitic stainless steel according to an embodiment of the present disclosure, the Charpy impact energy at -196°C may be 73 J or more.

[0077] In the austenitic stainless steel according to an embodiment of the present disclosure, the Charpy impact energy at -253°C may be 54 J or more. The Charpy impact energy at -253°C evaluates the impact toughness at -253°C, which is the temperature of liquid hydrogen, and can indicate whether the material has characteristics of excellent impact toughness in the liquid hydrogen environment where it is actually applied.

[0078] Next, a method for manufacturing an austenitic stainless steel according to the present disclosure will be described.

[0079] A method for manufacturing an austenitic stainless steel according to an embodiment of the present disclosure includes: preparing a slab comprising, in percent by weight (wt%), 0.10% or less of C (excluding 0), 1.50% or less of Si (excluding 0), 16 to 23% of Cr, 5.1 to 12% of Ni, 15% or less of Mn (excluding 0), 1.2% or less of Cu (excluding 0), 0.1 to 0.4% of N, 0.01% or less of (Nb+V), and the remainder of Fe and inevitable impurities, wherein a product of a strength index represented by Formula (1) below and a Stacking Fault Energy (SFE) represented by Formula (2) below is 0 or more; hot rolling the slab at a temperature of 1050 to 1300°C to manufacture a hot-rolled steel sheet; and annealing the hot-rolled steel sheet at a temperature of 900 to 1,200°C.

$$\text{Strength Index: (Yield Strength (MPa)) - 0.9Cr + 2Ni - 12Si - 1.1Mn - 80N + 400C - 275}$$

Formula (1)

$$\text{Formula (2) SFE: } 25.7 + 2\text{Ni} + 410\text{C} - 0.9\text{Cr} - 77\text{N} - 13\text{Si} - 1.2\text{Mn}$$

[0080] (In Formula (1) and Formula (2), Cr, Ni, Si, Mn, N, and C mean the content (wt%) of each element)

[0081] The role and content of each alloy composition, and descriptions regarding Formula (1) to Formula (4) are as described above.

[0082] In the process of annealing the hot-rolled steel sheet, the annealing temperature greatly affects the relief of residual stress and the microstructure. For example, the annealing temperature may be 900 to 1,200°C.

[0083] An annealing temperature of less than 900°C causes generation of coarse carbides, making the structure non-uniform, or formation of chromium carbide precipitates around grain boundaries, which may cause intergranular corrosion. However, an annealing temperature exceeding 1,200°C causes crystal grains to become extremely coarse. Considering this, it is preferable to limit the annealing temperature to 900 to 1200°C.

[0084] In the method for manufacturing an austenitic stainless steel according to an embodiment of the present

disclosure, the slab may further include 1.5% or less of Mo.

[0085] In the method for manufacturing an austenitic stainless steel according to an embodiment of the present disclosure, the slab may have Formula (3) being 0 or more.

$$\text{Formula (3): } (100N) + \text{Mn} - \text{Ni}$$

(wherein N, Mn, and Ni mean the content (wt%) of each element)

[0086] In the method for manufacturing an austenitic stainless steel according to an embodiment of the present disclosure, the slab may have a value of Formula (4) below being 0 or more.

$$(\text{Ni} + 0.52\text{Cu} + 40(\text{C} + \text{N}) + 0.7\text{Mn} + 45) - (0.48(\text{Cr} + \text{Mo} + 1.7\text{Si})) - 51$$

Formula (4):

(wherein Ni, Cu, C, N, Mn, Cr, Mo, and Si mean the content (wt%) of each element)

[0087] In the method for manufacturing an austenitic stainless steel according to an embodiment of the present disclosure, the hot rolling time in the manufacturing of the hot-rolled steel sheet may be 1 hour to 3 hours, and the annealing time in the annealing may be 5 minutes to 100 minutes.

[0088] The austenitic stainless steel manufactured under the manufacturing conditions according to the present disclosure may have values of Formula (1) * Formula (2), Formula (3), and Formula (4) being 0 or more, a delta ferrite fraction of 4% or less, a room temperature yield strength of 280 MPa or more, a -196°C Charpy impact energy of 73 J or more, and a -253°C Charpy impact energy of 54 J or more.

[0089] Hereinafter, the configuration and operation of the present disclosure will be described in more detail through preferred examples of the present disclosure. However, these are presented as preferred examples of the present disclosure and cannot be interpreted as limiting the present disclosure in any sense.

{Example}

[0090] Slabs having the compositions shown in Table 1 were manufactured, heated, and then hot rolled at 1,250°C for 2 hours. Thereafter, the hot-rolled steel sheets were annealed at 1000°C to 1200°C for 60 minutes or less to obtain specimens.

[0091] Table 1 below shows the component composition content (wt%) for each specimen. Underlines in Table 1 indicate those outside the scope of the present disclosure.

[Table 1]

	Alloy Composition (wt%)							
	C	Si	Mn	Cr	Ni	Mo	Cu	N
Example 1	0.02	0.43	3.6	18.8	8.8	-	0.38	0.17
Example 2	0.02	0.4	2.4	20.2	8.6	-	0.81	0.19
Example 3	0.02	0.39	7.5	17.2	5.9	-	0.39	0.19
Example 4	0.02	0.4	8.6	16.6	5.1	-	0.39	0.17
Example 5	0.02	0.42	0.9	21.6	10.4	0.6	0.79	0.2
Example 6	0.02	0.41	5.6	17.5	5.5	-	0.36	0.18
Example 7	0.02	0.43	4.5	18.2	8.4	-	1.17	0.15
Example 8	0.02	0.39	1.2	19.4	10.5	-	0.41	0.11
Example 9	0.03	0.4	13.2	16.1	5.3	-	0.41	0.11
Example 10	0.02	0.38	0.9	20.8	9.2	0.2	0.79	0.15
Example 11	0.03	0.41	11.4	16.5	5.1	-	0.8	0.14
Example 12	0.02	0.39	7	20.1	10.1	-	0.4	0.19
Example 13	0.02	0.41	4.1	19.2	8.5	-	0.43	0.2
Example 14	0.02	0.41	0.8	21.5	9.4	0.6	0.81	0.2
Example 15	0.02	0.42	7.2	17.7	7.3	-	0.4	0.17

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(continued)

	Alloy Composition (wt%)							
	C	Si	Mn	Cr	Ni	Mo	Cu	N
Compa rative Examp le 1	0. 02	0.6	1.3	18. 1	8.1	-	0.3	<u>0.0 5</u>
Compa rative Examp le 2	0. 02	0.5 2	8.8	16. 4	2.8	-	<u>1.8 9</u>	0.2 2
Compa rative Examp le 3	0. 02	0.4 5	1.3	16. 8	10. 1	<u>2.0 5</u>	0.2 7	<u>0.0 71</u>
Compa rative Examp le 4	0. 02	0.5 9	1.1	16. 1	10. 3	<u>2.1 1</u>	0.3 1	<u>0.0 16</u>
Compa rative Examp le 5	0. 03	0.3 8	14. 1	16. 1	2.5	-	0.3	0.2 5
Compa rative Examp le 6	0. 02	0.4 7	1.6	16. 7	9.6	-	0.4	<u>0.0 6</u>
Compa rative Examp le 7	0. 02	0.4 5	3.5	17. 2	6.2	0.8	0.1	0.2 8
Compa rative Examp le 8	0. 02	0.4	10	19. 3	5.3	-	0.2	0.2 1
Compa rative Example 9	0. 02	1.1	11. 6	22. 5	5.2	-	0.4	0.1 4

[0092] Yield strength was measured for the specimens by the following method.

[Yield Strength]

[0093] A plate-shaped sub-size tensile specimen with a thickness of 1.5 mm was manufactured, and the specimen was collected at a 1/2t point in the thickness direction of each specimen and measured according to ASTM E8 regulations. The average value of 5 measurements is shown, and it is expressed as 0.2% yield strength (YS0.2).

[0094] Table 2 shows the measured yield strength and the values of Formula (1), Formula (2) to Formula (4), and Formula (1) * Formula (2) calculated based thereon. Underlines mean those outside the scope of the present disclosure.

[Table 2]

	Yield Strengt h (MPa)	Form ula (1)	Form ula (2)	Formula (1) * Formula (2)	Form ula (3)	Form ula (4)
Examp l e 1	326.5	37.5	11.6	434	11.8	3.7
Examp l e 2	338.5	47.9	10.2	489	12.8	3.1
Examp l e3	313.8	15.0	1.5	23	20.6	5.2
Examp l e 4	337.7	38.1	0.5	21	20.5	4.6
Examp l e 5	361.5	73.8	13.3	983	10.5	3.2
Examp l e 6	334.7	37.5	3.2	121	18.1	2.9
Examp l e 7	318.8	30.1	11.8	355	11.1	3.9
Examp l e 8	282	3.7	22.5	84	1.7	1.1
Examp l e 9	333.6	38.6	4.6	178	18.9	6.3
Examp l e 10	341.6	56.7	16.0	908	6.7	0.7
Examp l e 11	324.5	28.2	3.6	100	20.3	6.0
Examp l e 12	324.3	31.8	7.9	252	15.9	7.6
Examp l e 13	329.8	37.1	8.0	296	15.6	4.8
Examp l e 14	350.8	61.5	11.7	717	11.4	2.2
Examp l e 15	327.5	32.6	5.4	175	16.9	5.3
Compa rative Examp l e 1	<u>254.1</u>	-25.6	20.6	<u>-528</u>	<u>-1.8</u>	<u>-3.2</u>
Compa rative Examp l e 2	374.1	64.4	-9.5	<u>-613</u>	28.0	5.2
Compa rative Examp l e 3	<u>270.6</u>	-3.8	26.1	<u>-100</u>	<u>-1.7</u>	<u>-0.6</u>

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(continued)

	Yield Strengt h (MPa)	Form ula (1)	Form ula (2)	Formula (1) * Formula (2)	Form ula (3)	Form ula (4)
Compa rative Exampl e 4	<u>237.7</u>	-32.8	29.8	<u>-976</u>	<u>-7.6</u>	<u>-2.6</u>
Compa rative Example 5	370	57.4	-12.6	<u>-724</u>	36.6	9.7
Compa rative Exampl e 6	<u>263.4</u>	-11.6	25.4	<u>-296</u>	<u>-2.0</u>	<u>-0.3</u>
Compa rative Exampl e 7	393	91.3	-0.8	<u>-72</u>	25.3	5.7
Compa rative Exampl e 8	378	71.6	-6.2	<u>-447</u>	25.7	6.0
Compa rative Exampl e 9	335	21.0	-15.0	<u>-314</u>	20.4	2.2

[0095] Subsequently, the delta ferrite content, Charpy impact energy at -196°C, and Charpy impact energy at -253°C were measured for the specimens. The measurement methods are as follows. [Delta Ferrite Content]

[0096] Five points were randomly selected from the center of each specimen after hot rolling, and the delta ferrite content was measured using a ferrite scope, and then the average value was taken. The center of the specimen means a 1/4 to 3/4t point when the total thickness direction length is t.

[Charpy Impact Energy at -196°C, Charpy Impact Energy at -253°C]

[0097] After manufacturing an ASTM E23 type A specimen standard, Charpy impact energy at -196°C and -253°C was measured using a Charpy impact tester at temperatures of -196°C and -253°C. After performing the same experiment 5 times for each specimen, the average value of the 5 measured values was taken.

[0098] Table 3 below shows the physical properties, and underlines mean those outside the scope of the present disclosure.

[Table 3]

	Yield Strength (MPa)	Delta Ferrite Content (Area %)	-196°C Charpy Impact Energy (J)	-253°C Charpy Impact Energy (J)
Exam ple 1	326.5	1 or less	128	111
Exam ple 2	338.5	1 or less	130	115
Exam ple 3	313.8	1 or less	113	109
Exam ple 4	337.7	1.7	106	95
Exam ple 5	361.5	1.2	126	110
Exam ple 6	334.7	1 or less	106	104
Exam ple 7	318.8	1 or less	121	108
Exam ple 8	282	1.5	188	136
Exam ple 9	333.6	3.1	86	67
Exam ple 10	341.6	2.7	121	106
Exam ple 11	324.5	3.4	73	54
Exam ple 12	324.3	1 or less	128	109
Exam ple 13	329.8	1 or less	151	117
Exam ple 14	350.8	2.3	126	118
Exam ple 15	327.5	1 or less	131	116
Comp arative Exam ple 1	<u>254.1</u>	1.1	110	95
Comp arative Exam ple 2	374.1	<u>4.2</u>	<u>35</u>	<u>18</u>
Comp arative Exam ple 3	<u>270.6</u>	1 or less	156	111
Comp arative Exam ple 4	<u>237.7</u>	1.2	165	120

(continued)

	Yield Strength (MPa)	Delta Ferrite Content (Area %)	-196°C Charpy Impact Energy (J)	-253°C Charpy Impact Energy (J)
Comparative Example 5	370	<u>4.4</u>	<u>32</u>	<u>20</u>
Comparative Example 6	<u>263.4</u>	1 or less	135	118
Comparative Example 7	393	1 or less	<u>42</u>	<u>25</u>
Comparative Example 8	378	1 or less	<u>47</u>	<u>19</u>
Comparative Example 9	335	<u>4.6</u>	<u>38</u>	<u>22</u>

[0099] Examples 1 to 15 are specimens that satisfy the alloy composition disclosed in the present disclosure and satisfy the scope of the present disclosure as the values of Formula (1) * Formula (2), Formula (3), and Formula (4) appear as positive numbers, and Examples 1 to 15 secured a yield strength of 280 MPa or more, a delta ferrite content of 4% or less, a Charpy impact energy at -196°C of 73 J or more, and a Charpy impact energy at -253°C of 54 J or more, thereby having high strength and excellent low-temperature impact toughness. Comparative Examples 1, 3, 4, and 6 are specimens with insufficient N content. Accordingly, the solid solution strengthening effect by N was not sufficient, so a yield strength of 280 MPa or more was not secured. Accordingly, the values of Formula (1) * Formula (2), Formula (3), and Formula (4) appeared as negative numbers, and stainless steel excellent in both yield strength and low-temperature impact toughness was not obtained. In Comparative Examples 2, 5, and 9, the value of Formula (1) * Formula (2) appeared as a negative number, and the delta ferrite fraction exceeded 4%, so low-temperature impact toughness was deteriorated.

[0100] In Comparative Examples 7 and 8, the value of Formula (1) * Formula (2) appeared as a negative number, so low-temperature impact toughness was deteriorated.

[0101] Through these Examples and Comparative Examples, it can be seen that in order to provide an austenitic stainless steel with excellent yield strength and low-temperature impact toughness, it is necessary to essentially include N contributing to securing yield strength, while optimizing alloy elements by controlling Formula (1) to Formula (4) in consideration of alloy elements such as Ni and Mn.

[0102] Although described with reference to the above embodiments, those skilled in the art will understand that the present disclosure can be variously modified and changed without departing from the spirit and scope of the present disclosure described in the claims below.

Claims

1. An austenitic stainless steel comprising, in percent by weight (wt%), 0.10% or less of carbon (C) (excluding 0), 1.50% or less of silicon (Si) (excluding 0), 16 to 23% of chromium (Cr), 5.1 to 12% of nickel (Ni), 15% or less of manganese (Mn) (excluding 0), 1.2% or less of copper (Cu) (excluding 0), 0.1 to 0.4% of nitrogen (N), 0.01% or less of (Nb+V), and the remainder of iron (Fe) and inevitable impurities, wherein a product of a strength index represented by Formula (1) below and a Stacking Fault Energy (SFE) represented by Formula (2) below is 0 or more.

$$\text{Strength Index: (Yield Strength (MPa)) - 0.9Cr + 2Ni - 12Si - 1.1Mn - 80N + 400C - 275}$$

Formula (1)

$$\text{Formula (2) SFE: } 25.7 + 2\text{Ni} + 410\text{C} - 0.9\text{Cr} - 77\text{N} - 13\text{Si} - 1.2\text{Mn}$$

(In Formula (1) and Formula (2), Cr, Ni, Si, Mn, N, and C mean the content (wt%) of each element)

2. The austenitic stainless steel according to claim 1, further comprising 1.5% or less of molybdenum (Mo) (excluding 0).
3. The austenitic stainless steel according to claim 1, wherein a value of Formula (1) is 0 to 100.
4. The austenitic stainless steel according to claim 1, wherein a value of Formula (2) is 0 to 40.

5. The austenitic stainless steel according to claim 1, wherein a value of Formula (3) below is 0 or more.

$$\text{Formula (3): } (100N) + \text{Mn} - \text{Ni}$$

(wherein N, Mn, and Ni mean the content (wt%) of each element)

6. The austenitic stainless steel according to claim 2, wherein a value of Formula (4) below is 0 or more.

$$\text{Formula (4): } (\text{Ni} + 0.52\text{Cu} + 40(\text{C} + \text{N}) + 0.7\text{Mn} + 45) - (0.48(\text{Cr} + \text{Mo} + 1.7\text{Si})) - 51$$

(wherein Ni, Cu, C, N, Mn, Cr, Mo, and Si mean the content (wt%) of each element)

7. The austenitic stainless steel according to claim 1, wherein a content of delta ferrite is 4% or less by area fraction.

8. The austenitic stainless steel according to claim 1, having a yield strength of 280 MPa or more.

9. The austenitic stainless steel according to claim 1, having a Charpy impact energy of 73 J or more at -196°C.

10. The austenitic stainless steel according to claim 1, having a Charpy impact energy of 54 J or more at -253°C.

11. A method for manufacturing an austenitic stainless steel, the method comprising:

preparing a slab comprising, in percent by weight (wt%), 0.10% or less of carbon (C) (excluding 0), 1.50% or less of silicon (Si) (excluding 0), 16 to 23% of chromium (Cr), 5.1 to 12% of nickel (Ni), 15% or less of manganese (Mn) (excluding 0), 1.2% or less of copper (Cu) (excluding 0), 0.1 to 0.4% of nitrogen (N), 0.01% or less of (Nb+V), and the remainder of iron (Fe) and inevitable impurities, wherein a product of a strength index represented by Formula (1) below and a Stacking Fault Energy (SFE) represented by Formula (2) below is 0 or more;

hot rolling the slab at a temperature of 1050 to 1300°C to manufacture a hot-rolled steel sheet; and annealing the hot-rolled steel sheet at a temperature of 900 to 1,200°C.

$$\text{Strength Index: (Yield Strength (MPa))} - 0.9\text{Cr} + 2\text{Ni} - 12\text{Si} - 1.1\text{Mn} - 80\text{N} + 400\text{C} - 275 \quad \text{Formula (1)}$$

$$\text{Formula (2) SFE: } 25.7 + 2\text{Ni} + 410\text{C} - 0.9\text{Cr} - 77\text{N} - 13\text{Si} - 1.2\text{Mn}$$

(In Formula (1) and Formula (2), Cr, Ni, Si, Mn, N, and C mean the content (wt%) of each element)

12. The method for manufacturing an austenitic stainless steel according to claim 11, wherein the slab further comprises 1.5% or less of molybdenum (Mo) (excluding 0).

13. The method for manufacturing an austenitic stainless steel according to claim 11, wherein a value of Formula (3) below is 0 or more.

$$\text{Formula (3): } (100N) + \text{Mn} - \text{Ni}$$

(wherein N, Mn, and Ni mean the content (wt%) of each element)

14. The method for manufacturing an austenitic stainless steel according to claim 12, wherein a value of Formula (4) below is 0 or more.

$$\text{Formula (4): } (\text{Ni} + 0.52\text{Cu} + 40(\text{C} + \text{N}) + 0.7\text{Mn} + 45) - (0.48(\text{Cr} + \text{Mo} + 1.7\text{Si})) - 51$$

(wherein Ni, Cu, C, N, Mn, Cr, Mo, and Si mean the content (wt%) of each element)

15. The method for manufacturing an austenitic stainless steel according to claim 11, wherein

a hot rolling time in the manufacturing of the hot-rolled steel sheet is 1 hour to 3 hours, and
an annealing time in the annealing is 5 minutes to 100 minutes.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/020189

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/58(2006.01)i; **C22C 38/42**(2006.01)i; **C22C 38/46**(2006.01)i; **C22C 38/48**(2006.01)i; **C22C 38/44**(2006.01)i;
C21D 8/02(2006.01)i; **C21D 9/46**(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 38/58(2006.01); C21D 8/02(2006.01); C22C 38/00(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: 스테인리스강(stainless steel), 오스테나이트(austenite), 크롬(Cr), 니켈(Ni), 구리(Cu), 니오븀(Nb), 바나듐(V), 몰리브덴(Mo), 열간 압연(hot rolling), 소둔(annealing)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2021-139008 A (NIPPON STEEL CORP.) 16 September 2021 (2021-09-16) See paragraphs [0058] and [0061]-[0063], claim 1 and table 2.	1-15
X	JP 2016-183412 A (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORP.) 20 October 2016 (2016-10-20) See paragraphs [0051]-[0052] and [0059] and claims 1, 3 and 5.	1-15
X	KR 10-2016-0018748 A (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORPORATION) 17 February 2016 (2016-02-17) See paragraph [0066], claims 1 and 5 and table 2.	1-15
A	JP 2023-148079 A (NIPPON STEEL STAINLESS STEEL CORP.) 13 October 2023 (2023-10-13) See paragraph [0060] and claims 1-2.	1-15
A	JP 2022-069229 A (NIPPON STEEL STAINLESS STEEL CORP.) 11 May 2022 (2022-05-11) See claims 1-3 and 6.	1-15

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

“A” document defining the general state of the art which is not considered to be of particular relevance

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“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 26 March 2025	Date of mailing of the international search report 26 March 2025
Name and mailing address of the ISA/KR Korean Intellectual Property Office Government Complex-Daejeon Building 4, 189 Cheongsaro, Seo-gu, Daejeon 35208 Facsimile No. +82-42-481-8578	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
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