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(71) Applicant: **POSCO Co., Ltd**
Pohang-si, Gyeongsangbuk-do 37859 (KR)

(72) Inventors:
- **SONG, Seokweon**
Pohang-si Gyeongsangbuk-do 37701 (KR)
- **KIM, Kwangmin**
Pohang-si Gyeongsangbuk-do 37669 (KR)
- **LEE, Hongju**
Pohang-si Gyeongsangbuk-do 37655 (KR)
- **KIM, Inho**
Wanju-gun Jeollabuk-do 55316 (KR)

(74) Representative: **Nederlandsch Octrooibureau**
P.O. Box 29720
2502 LS The Hague (NL)

(54) **AUSTENITIC STAINLESS STEEL HAVING EXCELLENT LOW-TEMPERATURE IMPACT TOUGHNESS AND METHOD FOR MANUFACTURING SAME**

(57) According to an embodiment of the present invention, an austenitic stainless steel comprising, in weight percentage, C: 0.03% or less (excluding 0), N: 0.15 to 0.25%, Si: 1.0% or less (excluding 0), Mn: 3.3 to 7.5%, Cr: 17.0 to 22.0%, Ni: 6.5 to 9.5%, Cu: 1.2% or less (excluding 0), Mo: 0.8% or less (excluding 0), and the balance being Fe and inevitable impurities, wherein the austenitic stainless steel satisfies formula (1): 70≤(100-ASP)/(Ni/Mn)≤170, and the Charpy impact energy at -196°C is 120 J or more (where ASP represents the austenite phase stability and ASP is calculated by 551-462(C+N)-9.2Si-8.1Mn-13.7Cr-29(Ni+Cu)-18.5Mo (Ni and Mn represent the weight percentages of respective elements thereof).

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Description

[Technical Field]

[0001] The present disclosure relates to an austenitic stainless steel, and more specifically, to an austenitic stainless steel having high strength and excellent low-temperature impact properties applicable to parts, equipment, and tanks for the purpose of storage, transportation, and use of LNG, liquefied ammonia, liquid nitrogen, liquefied CO_2, liquefied hydrogen, and the like.

[Background Art]

[0002] Stainless steels with excellent corrosion resistance are advantageous materials for use in various parts, equipment, and structural materials directly exposed to external environments because they do not require separate investment in facilities for improving corrosion resistance. Particularly, in the case of austenitic stainless steels, excellent formability and elongation thereof enable formation of shapes according to various customer requirements and provide aesthetically pleasing appearances. In addition, because austenitic stainless steels do not embrittle at low temperature due to inherent properties thereof, excellent impact properties may be obtained at low temperature and austenitic stainless steels are used in the industry as materials suitable for use in cryogenic environments such as LNG, liquefied ammonia, liquid nitrogen, liquefied CO_2, and liquefied hydrogen.

[0003] However, general austenitic stainless steels have a yield strength of 250 MPa or less, which limits application thereof in various uses, and martensite phase transformation observed in metastable austenitic stainless steels causes deterioration in impact properties, thereby acting as a factor hindering use in cryogenic environments.

[0004] In conventional products, high-priced elements were used to improve austenite phase stability and prevent martensite phase transformation, and Ni has been actively used to improve austenite phase stability. However, excessive addition of Ni, a high-priced element with unstable supply and extreme price fluctuation, has limitations in terms of price competitiveness.

[0005] Therefore, there is a need to develop austenitic stainless steels having high yield strength and excellent impact properties with high austenite phase stability compared to manufacturing costs by overcoming problems of conventional general-purpose austenitic stainless steels.

[Disclosure]

[Technical Problem]

[0006] The present disclosure has been proposed to solve the above-described problems, and provided are an austenitic stainless steel having high yield strength and excellent impact properties with high austenite phase stability compared to manufacturing costs and a method for manufacturing the same.

[0007] However, the technical problems to be solved by the present disclosure are not limited to the aforementioned problems, and any other technical problems not mentioned herein will be clearly understood from the following description by those skilled in the art to which the present disclosure pertains.

[Technical Solution]

[0008] An austenitic stainless steel according to an embodiment of the present disclosure to achieve the above-described object includes, in percent by weight (wt%), 0.03% or less (excluding 0) of C, 0.15 to 0.25% of N, 1.0% or less (excluding 0) of Si, 3.3 to 7.5% of Mn, 17.0 to 22.0% of Cr, 6.5 to 9.5% of Ni, 1.2% or less (excluding 0) of Cu, 0.8% or less (excluding 0) of Mo, and the balance of Fe and inevitable impurities, wherein the austenitic stainless steel satisfies Formula (1) below and has a Charpy impact energy at -196°C of 120 J or more:

$$\text{Formula (1): } 70 \leq (100 - ASP) / (Ni / Mn) \leq 170$$

(wherein ASP represents austenite phase stability, ASP is calculated by 551-462(C+N)-9.2Si-8.1Mn-13.7Cr-29(Ni+Cu)-18.5Mo, and Ni and Mn represent wt% of the respective elements).

[0009] In addition, in the austenitic stainless steel according to an embodiment of the present disclosure, austenitic stainless steel may satisfy Formula (2) below.

[0010] Formula (2): 1.45Mn + 10Ni - 9.5Cu - 175N + 0.32(CVN@25°C) ≥ 120 (wherein Mn, Ni, Cu, and N represent wt%

of the respective elements, and CVN@25°C refers to a Charpy impact energy value at 25°C).

[0011] In addition, in the austenitic stainless steel according to an embodiment of the present disclosure, the austenitic stainless steel may satisfy Formula (3) below.

$$\text{Formula (3): } 4.4 + 23(C + N) + 1.3Si + 0.24(Cr + Ni + Mn) \geq 16$$

(wherein C, N, Si, Cr, Ni, and Mn represent wt% of the respective elements.)

[0012] In addition, in the austenitic stainless steel according to an embodiment of the present disclosure, a yield strength may be 300 MPa or more.

[0013] A method for manufacturing an austenitic stainless steel according to an embodiment of the present disclosure includes: manufacturing a slab including, in percent by weight (wt%), 0.03% or less (excluding 0) of C, 0.15 to 0.25% of N, 1.0% or less (excluding 0) of Si, 3.3 to 7.5% of Mn, 17.0 to 22.0% of Cr, 6.5 to 9.5% of Ni, 1.2% or less (excluding 0) of Cu, 0.8% or less (excluding 0) of Mo, and the balance of Fe and inevitable impurities, and satisfying Formula (1) below; heating and extracting the slab; hot rolling and hot annealing the extracted slab to a hot-rolled steel sheet; and cold rolling and cold annealing the hot-rolled steel sheet, wherein a Charpy impact energy value at-196°C is 120 J or more

$$\text{Formula (1): } 70 \leq (100 - ASP) / (Ni / Mn) \leq 170$$

(wherein ASP represents austenite phase stability, ASP is calculated by 551-462(C+N)-9.2Si-8.1Mn-13.7Cr-29(Ni+Cu)-18.5Mo, and Ni and Mn represent wt% of the respective elements).

[0014] In addition, in the method for manufacturing an austenitic stainless steel according to an embodiment of the present disclosure, the austenitic stainless steel may satisfy Formula (2) below.

[0015] Formula (2): 1.45Mn + 10Ni - 9.5Cu - 175N + 0.32(CVN@25°C) ≥ 120 (wherein Mn, Ni, Cu, and N represent wt% of the respective elements, and CVN@25 °C refers to a Charpy impact energy value at 25°C).

[0016] In addition, in the method for manufacturing an austenitic stainless steel according to an embodiment of the present disclosure, the austenitic stainless steel may satisfy Formula (3) below and have a yield strength of 300 MPa or more:

$$\text{Formula (3): } 4.4 + 23(C + N) + 1.3Si + 0.24(Cr + Ni + Mn) \geq 16$$

(wherein C, N, Si, Cr, Ni, and Mn represent wt% of the respective elements).

[0017] In addition, in the method for manufacturing an austenitic stainless steel according to an embodiment of the present disclosure, the heating and extracting of the slab may be performed at 1080 to 1280 °C.

[0018] In addition, in the method for manufacturing an austenitic stainless steel according to an embodiment of the present disclosure, the hot rolling may be performed at 800°C or above at a reduction ratio of 70%.

[0019] In addition, in the method for manufacturing an austenitic stainless steel according to an embodiment of the present disclosure, the hot annealing may be performed at 1000 to 1200°C for 60 minutes.

[0020] In addition, the method for manufacturing an austenitic stainless steel according to an embodiment of the present disclosure may further include a cooling process after the hot rolling and before the hot annealing, wherein the cooling process is performed at a cooling rate of 50°C /s or less.

[0021] In addition, in the method for manufacturing an austenitic stainless steel according to an embodiment of the present disclosure, the cold rolling may be performed at room temperature at a reduction ratio of 50% or more.

[0022] In addition, in the method for manufacturing an austenitic stainless steel according to an embodiment of the present disclosure, the cold annealing may be performed at 1000 to 1200°C for 10 minutes or less.

[Advantageous Effects]

[0023] According to an embodiment of the present disclosure, provided are an austenitic stainless steel having excellent impact toughness from room temperature to ultra-low temperature by improving austenite phase stability compared to manufacturing costs by controlling the Ni and Mn ratio and preventing phase transformation at low temperature, and a method for manufacturing the same. In addition, according to an embodiment of the present disclosure, an austenitic stainless steel also having excellent yield strength and a method for manufacturing the same may be provided.

[Best Mode]

[0024] An austenitic stainless steel according to an embodiment of the present disclosure includes, in percent by weight (wt%), 0.03% or less (excluding 0) of C, 0.15 to 0.25% of N, 1.0% or less (excluding 0) of Si, 3.3 to 7.5% of Mn, 17.0 to 22.0% of Cr, 6.5 to 9.5% of Ni, 1.2% or less (excluding 0) of Cu, 0.8% or less (excluding 0) of Mo, and the balance of Fe and inevitable impurities, wherein the austenitic stainless steel satisfies Formula (1) below and has a Charpy impact energy at -196°C of 120 J or more:

$$\text{Formula (1): } 70 \leq (100 - \text{ASP}) / (\text{Ni} / \text{Mn}) \leq 170$$

[0025] (ASP represents austenite phase stability, ASP is calculated by 551-462(C+N)-9.2Si-8.1Mn-13.7Cr-29(Ni+Cu)-18.5Mo, and Ni and Mn represent wt% of the respective elements).

[Modes of the Invention]

[0026] Hereinafter, embodiments of the present disclosure will be described. However, the present disclosure may be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the concept of the invention to those skilled in the art.

[0027] The terms used herein are merely used to describe particular embodiments. Therefore, an expression used in the singular encompasses the expression of the plural, unless it should be clearly singular in the context. In addition, it is to be understood that the terms such as "including" or "having" are intended to indicate the existence of features, steps, functions, components, or combinations thereof disclosed in the specification, and are not intended to preclude the possibility that other features, steps, functions, components, or combinations thereof may exist or may be added.

[0028] Meanwhile, unless otherwise defined, all terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. Thus, these terms should not be interpreted in an idealized or overly formal sense unless expressly so defined herein. As used herein, the singular forms are intended to include the plural forms as well, unless the context clearly indicates otherwise.

[0029] Also, the terms "about", "substantially", etc. used throughout the specification means that when an inherent manufacturing and material tolerance is suggested, the tolerance corresponds to a value or is close to the value, and such values are intended for the sake of clear understanding of the present disclosure or to prevent an unconscious infringer from illegally using the disclosure of the present invention.

[0030] An austenitic stainless steel according to an embodiment of the present disclosure may include, in percent by weight (wt%), 0.03% or less (excluding 0) of C, 0.15 to 0.25% of N, 1.0% or less (excluding 0) of Si, 3.3 to 7.5% of Mn, 17.0 to 22.0% of Cr, 6.5 to 9.5% of Ni, 1.2% or less (excluding 0) of Cu, 0.8% or less (excluding 0) of Mo, and the balance of Fe and inevitable impurities.

[0031] Hereinafter, reasons for numerical limitations on the contents of alloying elements in the embodiment of the present disclosure will be described.

[0032] The content of C may be 0.03 wt% or less (excluding 0).

[0033] C, as an effective element for stabilization of an austenite phase, may be added to obtain yield strength of an austenitic stainless steel. However, an excess of C may induce grain boundary precipitation of a Cr carbide to impair ductility, toughness, corrosion resistance, and the like. Therefore, an upper limit of the C content may be controlled to 0.03%. Preferably, the C content may be 0.010% to 0.025%.

[0034] The content of N may be 0.15 to 0.25 wt%.

[0035] N, as a strong austenite-stabilizing element, is an effective element for improvement of yield strength of an austenitic stainless steel ana may be added in an amount of 0.15% or more. However, an excess of N may impair impact toughness in cryogenic environments. Also, problems that make manufacturing difficult, such as formation of pin holes, may occur. Therefore, an upper limit of the N content may be controlled to 0.25%.

[0036] The content of Si may be 1.0 wt% or less (excluding 0).

[0037] Si serves as a deoxidizer during a steelmaking process and may be added as an effective element for improvement of strength of a steel material. However, an excess of Si, which is also an effective element for stabilization of a ferrite phase, may not only promote formation of delta (δ) ferrite in a cast slab adversely affecting manufacturing, but also impair ductility and impact properties of a steel material. Therefore, an upper limit of the Si content may be controlled to 1.0%. Preferably, the Si content may be Si 0.3 to 0.8%.

[0038] The content of Mn may be 3.3 to 7.5 wt%.

[0039] Mn, as an austenite phase-stabilizing element added as a Ni substitute, may be added in an amount of 3.3% or more to improve austenite stability. However, an excess of Mn may cause excessive formation of S-based inclusions (MnS) to impair ductility, toughness, and corrosion resistance of the austenitic stainless steel, generate Mn fume during a steelmaking process to cause manufacturing risks, and induce planar slip behavior to impair impact toughness in cryogenic environments. Therefore, an upper limit of the Mn content may be controlled to 7.5%.

[0040] The content of Cr may be 17.0 to 22.0 wt%.

[0041] Although Cr is a ferrite-stabilizing element, Cr is an effective element for inhibiting formation of a martensite phase and may be added in an amount of 17.0% or more as a basic element for obtaining corrosion resistance required in stainless steels. However, an excess of Cr may increase manufacturing costs and form a large amount of delta (δ)-ferrite in a slab impairing hot workability and adversely affecting properties. Therefore, an upper limit of the Cr content may be controlled to 22.0%.

[0042] The content of Ni may be 6.5 to 9.5 wt%.

[0043] Ni, as a strong austenite phase-stabilizing element, is essential for obtaining excellent hot workability. However, because Ni is a high-priced element, addition of a large amount of Ni may cause an increase in manufacturing costs. Therefore, in consideration of costs and efficiency of a steel material, an upper limit of the Ni content may be controlled to 9.5%. Preferably, the Ni content may be 6.5 to 9.1%.

[0044] The content of Cu may be 1.2 wt% or less (excluding 0).

[0045] Cu, as an austenite phase-stabilizing element, is added as a Ni substitute in the present disclosure. Cu may be added to enhance corrosion resistance under a reducing environment. However, an excess of Cu may cause problems of impairing corrosion resistance, strength, and properties and decreasing productivity. Therefore, in consideration of efficiency and properties of a steel material, an upper limit of the Cu content may be controlled to 1.2%.

[0046] The content of Mo may be 0.8 wt% or less (excluding 0).

[0047] Mo, together with Cr, is an effective element for corrosion resistance and significantly contributes to solid solution strengthening effect. However, an excess of Mo may not only impair hot workability but also increase manufacturing costs because Mo is a high-priced element. Therefore, an upper limit of the Mo content may be controlled to 0.8%. Preferably, the upper limit of the Mo content may be controlled to 0.6%.

[0048] Also, the austenitic stainless steel according to an embodiment of the present disclosure may further include at least one of 0.035% or less of P and 0.01% or less of S as inevitable impurities.

[0049] The content of P may be 0.035% or less.

[0050] P, as an impurity inevitably contained in steels, is a major causative element of grain boundary corrosion or deterioration of hot workability, and therefore, it is preferable to control the P content as low as possible. In the present disclosure, an upper limit of the P content may be controlled to 0.035% or less.

[0051] The content of S may be 0.01% or less.

[0052] S, as an impurity that is inevitably contained in steels, is segregated in grain boundaries serving as a major causative element of deterioration of hot workability, and therefore, it is preferable to control the S content as low as possible. In the present disclosure, an upper limit of the S content may be controlled to 0.01% or less.

[0053] The remaining component of the composition of the present disclosure is iron (Fe). However, the composition may include unintended impurities inevitably incorporated from raw materials or surrounding environments. In the present disclosure, addition of other unintended alloying elements is not excluded. The impurities are not specifically mentioned in the present disclosure, as they are known to any person skilled in the art.

[0054] The austenitic stainless steel according to an embodiment of the present disclosure may satisfy Formula (1).

$$\text{Formula (1): } 70 \leq (100 - ASP) / (Ni / Mn) \leq 170$$

[0055] Herein, ASP represents austenite phase stability, and Ni and Mn represent wt% of the respective elements.

[0056] Herein, ASP may be obtained by 551 - 462(C + N) - 9.2Si - 8.1Mn - 13.7Cr - 29(Ni + Cu) - 18.5Mo.

[0057] ASP is a value representing an austenite phase stability of an austenitic stainless steel. As the ASP value decreases, martensite phase transformation occurs less at a low temperature, so that brittleness may be prevented in cryogenic environments. Ni and Mn are two representative elements improving austenite phase stability. Assuming that phase stabilities are same, price competitiveness may increase at a lower Ni/Mn value. Formula (1) is an index using the ASP and the Ni/Mn value.

[0058] A value of Formula (1) less than 70 indicates that the Ni content is excessive when the austenite phase stabilities are same, and price competitiveness may be low. In the case where the value of Formula (1) is greater than 170, austenite phase stability may decrease or the Mn content may be excessive, thereby causing deterioration of material properties. Therefore, in the present disclosure, the values of Formula (1) may be controlled to 70 to 170.

[0059] In the present disclosure, excellent austenite phase stability compared to manufacturing costs may be obtained by controlling the value of Formula (1) within the range of 70 to 170. By preventing martensite phase transformation by increasing austenite phase stability, impact properties may be obtained even in cryogenic environments.

[0060] In the present disclosure, a lower ASP means a higher austenite phase stability. In the present disclosure, ASP may be from -170 to -40. However, the present disclosure is not limited thereto. According to the present disclosure, by controlling the composition of alloying elements and Formula (1), the Ni/Mn value may decrease at the same ASP, so that excellent austenite phase stability compared to manufacturing costs may be obtained.

[0061] The austenitic stainless steel according to an embodiment of the present disclosure may have a Charpy impact energy value at -150°C of 145 J or more. In addition, the Charpy impact energy value at-196°C may be 120 J or more in the present disclosure.

[0062] In addition, the austenitic stainless steel according to an embodiment of the present disclosure may satisfy Formula (2) corresponding to an index of cryogenic impact toughness.

$$1.45Mn + 10Ni - 9.5Cu - 175N + 0.32(CVN@25°C) \geq 120 \quad \text{Formula (2):}$$

[0063] Herein, Mn, Ni, Cu, and N represent wt% of the respective elements, and CVN@25°C refers to a Charpy impact energy value at 25°C.

[0064] In the case where the value of Formula (2) is less than 120, excellent impact toughness may be obtained at room temperature, but movement of dislocation, which varies according to the ratios of alloying elements, may be affected so that rapid deterioration of impact toughness may be caused at a low temperature. Alternatively, in the case where the value of Formula (2) is less than 120, basic impact toughness at room temperature cannot be obtained. **In** this case, there may be a problem of failing to obtain sufficient impact toughness in cryogenic environments as well. Therefore, in the present disclosure, the value of Formula (2) may be controlled to 120 or more.

[0065] According to the present disclosure, impact toughness in cryogenic environments may be predicted by measuring room temperature Charpy impact energy value by measuring the Charpy impact energy value at 25°C by controlling the value of Formula (2) to 120 or more. An austenitic stainless steel having impact properties in cryogenic environments may be provided by expressing an impact toughness index in cryogenic environments using Formula (2).

[0066] In addition, the austenitic stainless steel according to an embodiment of the present disclosure may satisfy Formula (3) to consider improvement of yield strength .

$$\text{Formula (3): } 4.4 + 23(C + N) + 1.3Si + 0.24(Cr + Ni + Mn) \geq 16$$

[0067] Herein, C, N, Si, Cr, Ni, and Mn represent wt% of the respective elements.

[0068] According to the present disclosure, Formula (3) is derived to consider improvement of yield strength by stress field of a steel material to obtain high yield strength of the austenitic stainless steel.

[0069] In the case where the value of Formula (3) is less than 16, it is difficult to obtain the yield strength required in the present disclosure. Therefore, in the present disclosure, the value of Formula (3) may be controlled to 16 or more.

[0070] As the value of Formula (3) increases, a stress field between lattices increases due to atomic size difference between alloying elements, thereby increasing limits of plastic deformation while resisting external stress.

[0071] According to the present disclosure, an austenitic stainless steel having high strength may be provided by controlling the value of Formula (3) to 16 or more.

[0072] The austenitic stainless steel according to an embodiment of the present disclosure may have a yield strength of 300 MPa or more.

[0073] Hereinafter, a method for manufacturing an austenitic stainless steel including the above-described composition of alloying elements according to an embodiment of the present disclosure will be described.

[0074] The austenitic stainless steel according to the present disclosure may be manufactured by heating and extracting a slab having the above-described composition of alloying elements, followed by hot rolling - hot annealing - cold rolling - cold annealing processes. A cooling process may be performed before the hot annealing after the hot rolling.

[0075] A method for manufacturing an austenitic stainless steel according to the present disclosure may include: manufacturing a slab including, in percent by weight (wt%), 0.03% or less (excluding 0) of C, 0.15 to 0.25% of N, 1.0% or less (excluding 0) of Si, 3.3 to 7.5% of Mn, 17.0 to 22.0% of Cr, 6.5 to 9.5% of Ni, 1.2% or less (excluding 0) of Cu, 0.8% or less (excluding 0) of Mo, and the balance of Fe and inevitable impurities and satisfying Formula (1) below; heating and extracting the slab; hot rolling and hot annealing the extracted slab to a hot-rolled steel sheet; and cold rolling and cold annealing the hot-rolled steel sheet, wherein a Charpy impact energy at -196°C is 120 J or more.

$$\text{Formula (1): } 70 \leq (100 - ASP) / (Ni / Mn) \leq 170.$$

The composition of alloying elements, ASP, and Formula (1) are as described above in the austenitic stainless steel.

[0076] In addition, the method for manufacturing an austenitic stainless steel according to the present disclosure may be a method for manufacturing an austenitic stainless steel satisfying Formula (2) below.

[0077] Formula (2): 1.45Mn + 10Ni - 9.5Cu - 175N + 0.32(CVN@25°C) ≥ 120. The compositions of alloying elements, CVN@25°C, and Formula (2) are as described above in the austenitic stainless steel.

[0078] In addition, the method for manufacturing an austenitic stainless steel according to the present disclosure may be a method for manufacturing an austenitic stainless steel satisfying Formula (3) below.

$$\text{Formula (3): } 4.4 + 23(C + N) + 1.3Si + 0.24(Cr + Ni + Mn) \geq 16.$$

The compositions of alloying elements, and Formula (3) are as described above in the austenitic stainless steel.

[0079] After manufacturing the slab including the above-described composition of alloying elements, the heating and extracting processes may be performed at 1080 to 1280°C. In addition, the hot rolling may be a process performed at 800°C or above at a reduction ratio of 70%. In addition, the hot annealing may be a process performed at 1000 to 1200°C for 60 minutes. In addition, the method may further include a cooling process before the hot annealing after the hot rolling. The cooling process may be performed at a cooling rate of 50°C/s or less. In addition, the cold rolling may be a process performed at room temperature at a reduction ratio of 50% or more. In addition, the cold annealing may be a process performed at 1000 to 1200°C for 10 minutes or less. By performing the cold rolling and cold annealing after the hot annealing, and additional reduction in thickness may be intended.

[0080] The austenitic stainless steel manufactured by the method for manufacturing an austenitic stainless steel may have a Charpy impact energy value of 145 J or more at -150°C. In addition, the Charpy impact energy value at -196°C may be 120 J or more.

[0081] In addition, the austenitic stainless steel manufacturing by the method for manufacturing an austenitic stainless steel according the present disclosure may have a yield strength of 300 MPa or more.

[0082] The austenitic stainless steel of the present disclosure and the austenitic stainless steel manufactured by the method for manufacturing an austenitic stainless steel according to the present disclosure may have excellent austenite phase stability compared to manufacturing costs by controlling the ratio of Ni and Mn and low-temperature impact toughness by using the obtained austenite phase stability, simultaneously having strength.

Examples

[0083] Slabs respectively having compositions of alloying elements as shown in Table 1 below were prepared and heated and extracted at 1200°C. Also, each of the slabs was hot-rolled at 800°C at a reduction ratio of 70%, cooled at a cooling rate of 50°C/s, and hot-annealed at 1100°C for 60 minutes. In addition, the slab was cold-rolled at room temperature at a reduction ratio of 50% and cold-annealed at 1100°C for 10 minutes.

[0084] Yield strength YS (MPa), tensile strength TS (MPa), and elongation EL (%) obtained after conducting a tensile test on samples according to the JIS 13B standards at room temperature in a crosshead range of 10 mm/min to 20 mm/min and cryogenic (-150°C and -196°C) impact toughness (Charpy V notch test) measured according to the ASTM standards are shown. CVN@25°C refers to a Charpy impact energy value measured at 25°C.

[0085] Table 1 shows compositions of alloying elements, ASP, Ni/Mn ratios, Charpy impact energy values at -196°C, and vales of Formula (1).

Table 1

	Alloying elements					wt%)			ASP	Ni/M n	Formu la (1)	CVN @-19-6°C (J)
	C	Si	Mn	Ni	Cr	Cu	Mo	N				
Comparative Example 1	0.019	0.45	0.92	8.00	18.80	0.30	0.09	0.017	22.85	8.70	8.87	135.6
Comparative Example 2	0.020	0.61	1.10	10.20	16.10	0.31	2.11	0.016	-44.55	9.27	15.59	164.53
Comparative Example 3	0.021	0.47	1.28	10.09	21.20	0.27	0.11	0.071	-99.11	7.88	25.26	156.4
Comparative Example 4	0.023	0.41	0.81	10.40	21.50	0.79	0.6	0.200	-192.52	12.84	22.78	126.1
Comparative Example 5	0.021	0.42	0.80	9.31	21.30	0.81	0.6	0.200	-157.84	11.64	22.16	126.26
Comparative Example 6	0.021	0.38	7.63	5.98	17.40	0.39	0.14	0.190	-37.48	0.78	175.41	112.67

(continued)

	Alloying elements					wt%)			ASP	Ni/M n	Formu la (1)	CVN @-19-6°C (J)
	C	Si	Mn	Ni	Cr	Cu	Mo	N				
Comparative Example 7	0.021	0.38	7.62	5.46	17.50	0.39	0.12	0.210	-32.56	0.72	185.00	115.65
Comparative Example 8	0.022	0.39	9.80	5.40	17.60	0.39	0.2	0.190	-42.64	0.55	258.87	96.7
Comparative Example 9	0.021	0.38	7.80	5.90	18.20	0.40	0.15	0.210	-57.21	0.76	207.84	85.03
Comparative Example 10	0.020	0.54	8.90	2.80	16.80	1.89	0.15	0.220	-5.88	0.31	336.56	34.9
Comparative Example 11	0.022	0.39	7.90	5.00	16.80	0.39	0.11	0.180	1.59	0.63	155.48	102.76
Comparative Example 12	0.020	0.43	5.63	5.50	16.50	0.39	0.12	0.150	23.82	0.98	77.98	115.19
Comparative Example 13	0.020	0.39	5.65	5.60	17.30	0.36	0.08	0.180	-2.08	0.99	102.99	106.26
Comparative Example 14	0.021	0.40	5.93	5.60	18.00	0.37	0.09	0.190	-19.59	0.94	126.64	90.76
Comparative Example 15	0.019	0.41	2.49	8.57	20.40	0.81	0.08	0.190	-122.48	3.44	64.64	129.93
Comparative Example 16	0.019	0.40	1.22	9.25	19.60	0.81	0.13	0.150	-103.31	7.58	26.81	133.2
Comparative Example 17	0.019	0.40	1.18	10.30	19.40	0.41	0.13	0.110	-100.61	8.73	22.98	187.5
Inventive Example 1	0.022	0.43	7.20	7.40	17.90	0.40	0.13	0.170	-73.82	1.03	169.12	130.62
Inventive Example 2	0.019	0.41	5.60	7.20	17.40	0.41	0.21	0.170	-48.41	1.29	115.43	137.32
Inventive Example 3	0.019	0.41	3.44	8.90	18.90	0.38	0.2	0.170	-99.70	2.59	77.19	127.73
Inventive Example 4	0.019	0.40	4.10	8.50	19.00	0.43	0.18	0.200	-109.67	2.07	101.13	150.95
Inventive Example 5	0.019	0.41	3.60	8.38	20.20	0.80	0.09	0.190	-123.12	2.33	95.85	140.1
Inventive Example 6	0.020	0.41	4.60	7.83	17.90	1.07	0.08	0.200	-96.48	1.70	115.43	121.3
Inventive Example 7	0.019	0.41	4.51	8.40	18.00	1.17	0.15	0.150	-94.29	1.86	104.31	121.3

[0086] Table 2 shows values of Formula (2) and Formula (3) and mechanical properties.

Table 2

	Formula (2)	Formula (3)	YS (MPa)	TS (MPa)	EL (%)	CVN@25° C (J)	CVN@-150°C (J)	CVN@-196°C (J)
Comparative Example 1	141.56	12.47	264.5	661.3	56.8	206.40	149.3	135.6

(continued)

	Formul a (2)	Formu la (3)	YS (MPa)	TS (MPa)	EL (%)	CVN@25° C (J)	CV-N@-150°-C (J)	CV-N@-196°-C (J)
Comparative Example 2	177.19	12.60	237.7	555.6	69.9	247.93	181.21	164.53
Comparative Example 3	176.28	14.94	276.6	614.5	63.8	276.60	176	156.4
Comparative Example 4	138.85	17.91	361.5	677.1	52.4	238.06	160.1	126.1
Comparative Example 5	122.75	17.57	350.8	670.4	54.9	222.46	154.37	126.26
Comparative Example 6	119.45	17.19	313.8	651.0	64.4	267.31	159.61	112.67
Comparative Example 7	115.74	17.55	324.9	662.1	64.3	282.97	154.87	115.65
Comparative Example 8	103.61	17.66	346.2	658.7	64.2	226.12	132.01	96.7
Comparative Example 9	103.50	17.86	359.2	672.6	62.6	230.43	126.14	85.03
Comparative Example 10	62.05	17.46	374.1	677.2	62.8	242.50	85.5	34.9
Comparative Example 11	99.99	16.68	337.7	674.8	66.9	230.44	138.21	102.76
Comparative Example 12	104.93	15.50	284.3	682.3	66.9	224.12	143.47	115.19
Comparative Example 13	108.67	16.36	334.7	684.0	66.1	248.13	135.88	106.26
Comparative Example 14	101.68	16.86	353.1	683.3	64.9	230.77	127.22	90.76
Comparative Example 15	128.30	17.29	338.5	652.0	58.1	249.79	161.75	129.93
Comparative Example 16	137.19	16.02	305.3	615.1	61.3	240.20	162.8	133.2
Comparative Example 17	171.61	15.30	282.0	585.9	63.7	281.40	199.8	187.5
Inventive Ex-ample 1	129.45	17.18	327.5	635.3	62.9	245.50	163.06	130.62
Inventive Ex-ample 2	130.82	16.53	322.0	638.2	64.8	263.57	163.22	137.32
Inventive Ex-ample 3	137.70	16.78	326.5	634.1	59.8	240.85	163.39	127.73
Inventive Ex-ample 4	141.92	17.54	329.8	642.0	61.0	281.45	177.07	150.95
Inventive Ex-ample 5	130.26	17.46	344.0	652.3	57.7	256.52	160.91	140.1
Inventive Ex-ample 6	121.82	17.27	341.5	642.7	58.5	256.30	154.1	121.3

(continued)

	Formula (2)	Formula (3)	YS (MPa)	TS (MPa)	EL (%)	CVN@25° C (J)	CVN@-150°C (J)	CVN@-196°C (J)
Inventive Example 7	135.00	16.24	318.8	617.5	60.5	255.70	149.3	121.3

[0087] Referring to Tables 1 and 2, it may be confirmed that Inventive Examples 1 to 7 satisfy the composition of alloying elements of the present disclosure and have the values of Formula (1) of 70 to 170 indicating excellent austenite phase stability compared to manufacturing costs, and have Charpy impact energy values at -196°C not less than 120 J indicating excellent cryogenic impact toughness. In addition, the values of Formula (2) were not less than 120. The cryogenic impact toughness may be predicted by confirming room temperature impact toughness based on the 25°C Charpy impact energy values, and the cryogenic impact toughness may be confirmed based on the Charpy impact energy values at -150°C not less than 145 J and the Charpy impact energy values at -196°C not less than 120 J. In addition, because the values of Formula (3) are not less than 16 and the yield strengths are not less than 300 MPa, it may be confirmed that strength is obtained.

[0088] Although Comparative Examples 1 to 5 do not satisfy the composition of alloying elements of the present disclosure, the Charpy impact energy values at -196°C were not less than 120 J. However, the values of Formula (1) were less than 70 indicating that Ni is excessively added compared to the same-level austenite phase stability so that the Ni/Mn ratio is 7.88 or more. Therefore, it may be confirmed that excellent austenite phase stability is not obtained compared to manufacturing costs in the case where the composition of alloying elements and the lower limit of Formula (1) were not satisfied.

[0089] In addition, Comparative Examples 1 to 3 have the values of Formula (3) less than 16. The yield strengths of Comparative Examples 1 to 3 are less than 300 MPa, which do not satisfy the range of the present disclosure. Therefore, it may be confirmed that strength is inferior in the case where the value of Formula (3) is not satisfied.

[0090] It may be confirmed that Comparative Examples 6 to 10 have the values of Formula (1) exceeding 170 and the Mn contents exceeding 7.5%. In addition, because the Charpy impact energy value at -196°C is less than 120 J, it may be confirmed that low-temperature impact properties cannot be obtained. Because Comparative Examples 6 to 10 have the values of Formula (2) less than 120, it may be predicted that low-temperature impact toughness is not obtained, and the Charpy impact energy values at -150°C and the Charpy impact energy values at -196°C do not satisfy the ranges of the present disclosure. Therefore, it may be confirmed that excellent low-temperature impact toughness cannot be obtained in the case where the composition of alloying elements, the upper limit of Formula (1), and the value of Formula (2) are not satisfied.

[0091] Although Comparative Example 11 satisfies Formula (1), the value of Formula (2) is less than 120, so that the Charpy impact energy value at -150°C and the Charpy impact energy value at -196°C cannot satisfy the ranges of the present disclosure. Therefore, it may be confirmed that both excellent austenite phase stability compared to manufacturing costs and excellent low-temperature impact toughness cannot be obtained in the case where the composition of alloying elements and value of Formula (2) were not satisfied although excellent austenite phase stability compared to manufacturing costs may be obtained by satisfying the value of Formula (1).

[0092] Although Comparative Example 12 satisfies Formula (1), the value of Formula (2) is less than 120, so that the Charpy impact energy value at -150°C and the Charpy impact energy value at -196°C cannot satisfy the ranges of the present disclosure. In addition, because the value of Formula (3) is less than 16, the yield strength is less than 300 MPa failing to satisfy the range of the present disclosure. Therefore, it may be confirmed that both excellent austenite phase stability compared to manufacturing costs and excellent low-temperature impact toughness cannot be obtained in the case where the composition of alloying elements, and the values of Formula (2) and Formula (3) were not satisfied although excellent austenite phase stability compared to manufacturing costs may be obtained by satisfying Formula (1).

[0093] Comparative Examples 13 and 14 cannot satisfy the range of the Ni content according to the present disclosure. Based on the ASP values of -2.08 and -19.59, respectively, it may be confirmed that the austenite phase stability is low. Therefore, it may be confirmed that excellent phase stability cannot be obtained in the case where the composition of alloying elements is not satisfied although Formula (1) is satisfied. In addition, Comparative Examples 13 and 14 have values of Formula (2) less than 120. The Charpy impact energy value at -150°C and the Charpy impact energy value at -196°C do not satisfy the ranges of the present disclosure. Therefore, it may be confirmed that excellent low-temperature impact toughness cannot be obtained in the case where the value of Formula (2) is not satisfied.

[0094] Because Comparative Example 15 has a value of Formula (2) of 120 or more, the Charpy impact energy value at -150°C of 145 J or more and the Charpy impact energy value at -196°C of 120 J or more may be obtained. However, the value of Formula (1) is less than 70, so that price competitiveness is inferior in comparison with the same-level austenite phase stability. Comparative Example 15 has an ASP of -122.48 and an Ni/Mn ratio of 3.44. On the contrary, Inventive Example 5, which has the most similar ASP to that of Comparative Example 15, has an ASP of -123.12 and a Ni/Mn ratio of 2.33, which is smaller than that of Comparative Example 15, and Inventive Example 4, which has a higher ASP than that of Comparative Example 15, has an ASP of -109.67 and has a Ni/Mn ratio of 2.07, which is less than that of Comparative Example 15. Based thereon, it may be confirmed that excellent austenite phase stability compared to manufacturing costs cannot be obtained in the case where the composition of alloying elements and the lower limit of Formula (1) were not satisfied.

[0095] Because Comparative Example 16 has a value of Formula (2) of 120 or more, the Charpy impact energy value at -150°C of 145 J or more and the Charpy impact energy value at -196°C of 120 J or more may be obtained. However, the value of Formula (1) is less than 70, so that price competitiveness is inferior in comparison with the same-level austenite phase stability. Comparative Example 16 has an ASP of -103.31 and an Ni/Mn ratio of 7.58. On the contrary, Inventive Example 3, which has the most similar ASP to that of Comparative Example 16, has an ASP of -99.70 and a Ni/Mn ratio of 2.59, which is smaller than that of Comparative Example 16, and Inventive Example 4, which has a smaller ASP than that of Comparative Example 15, has an ASP of -109.67 and has a Ni/Mn ratio of 2.07, which is less than that of Comparative Example 16. Based thereon, it may be confirmed that excellent austenite phase stability compared to manufacturing costs cannot be obtained in the case where the composition of alloying elements and the lower limit of Formula (1) were not satisfied.

[0096] Because Comparative Example 17 has a value of Formula (2) of 120 or more, the Charpy impact energy value at -150°C of 145 J or more and the Charpy impact energy value at -196°C of 120 J or more may be obtained. However, the value of Formula (1) is less than 70, so that it may be confirmed that the Ni/Mn ratio is a large number of 8.73 due to the excess of Ni in comparison with the same-level austenite phase stability. In addition, price competitiveness of Comparative Example 17, whose value of Formula (1) is less than 70, is inferior in comparison with the same-level austenite phase stability. Comparative Example 17 has an ASP of -100.61 and an Ni/Mn ratio of 8.73. On the contrary, Inventive Example 3, which has the most similar ASP to that of Comparative Example 17, has an ASP of -99.70 and a Ni/Mn ratio of 2.59, which is smaller than that of Comparative Example 18, and Inventive Example 4, which has a smaller ASP of -109.67 and has a Ni/Mn ratio of 2.07, which is less than that of Comparative Example 17. Based thereon, it may be confirmed that excellent austenite phase stability compared to manufacturing costs cannot be obtained in the case where the composition of alloying elements and the lower limit of Formula (1) were not satisfied.

[0097] In addition, Comparative Example 17 has a value of Formula (3) less than 16 and a yield strength less than 300 MPa failing to satisfy the ranges of the present disclosure. Based thereon, it may be confirmed that strength is inferior in the case of failing to satisfy Formula (3).

[0098] While the present disclosure has been particularly described with reference to exemplary embodiments, it should be understood by those of skilled in the art that various changes in form and details may be made without departing from the spirit and scope of the present disclosure.

[Industrial Applicability]

[0099] The austenitic stainless steel according to an embodiment of the present disclosure had excellent impact toughness from room temperature to cryogenic environments by obtaining austenite phase stability compared to manufacturing costs, and excellent yield strength, and thus industrial applicability is possessed.

Claims

1. An austenitic stainless steel comprising, in percent by weight (wt%), 0.03% or less (excluding 0) of C, 0.15 to 0.25% of N, 1.0% or less (excluding 0) of Si, 3.3 to 7.5% of Mn, 17.0 to 22.0% of Cr, 6.5 to 9.5% of Ni, 1.2% or less (excluding 0) of Cu, 0.8% or less (excluding 0) of Mo, and the balance of Fe and inevitable impurities,

wherein the austenitic stainless steel satisfies Formula (1) below and has a Charpy impact energy at -196°C of 120 J or more:

$$\text{Formula (1)}: 70 \leq (100 - \text{ASP}) / (\text{Ni} / \text{Mn}) \leq 170$$

(wherein ASP represents austenite phase stability, ASP is calculated by 551-462(C+N)-9.2Si-8.1Mn-13.7Cr-29(Ni+Cu)-18.5Mo, and Ni and Mn represent wt% of the respective elements).

2. The austenitic stainless steel according to claim 1, wherein the austenitic stainless steel satisfies Formula (2) below:

$$\text{Formula (2): } 1.45Mn + 10Ni - 9.5Cu - 175N + 0.32(CVN@25°C) \geq 120$$

(wherein Mn, Ni, Cu, and N represent wt% of the respective elements, and CVN@25°C refers to a Charpy impact energy value at 25°C).

3. The austenitic stainless steel according to claim 1, wherein the austenitic stainless steel satisfies Formula (3) below:

$$\text{Formula (3): } 4.4 + 23(C + N)+1.3Si+0.24(Cr + Ni + Mn) \geq 16$$

(wherein C, N, Si, Cr, Ni, and Mn represent wt% of the respective elements).

4. The austenitic stainless steel according to claim 1, wherein a yield strength is 300 MPa or more.

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

manufacturing a slab comprising, in percent by weight (wt%), 0.03% or less (excluding 0) of C, 0.15 to 0.25% of N, 1.0% or less (excluding 0) of Si, 3.3 to 7.5% of Mn, 17.0 to 22.0% of Cr, 6.5 to 9.5% of Ni, 1.2% or less (excluding 0) of Cu, 0.8% or less (excluding 0) of Mo, and the balance of Fe and inevitable impurities, and satisfying Formula (1) below;
heating and extracting the slab;
hot rolling and hot annealing the extracted slab to a hot-rolled steel sheet; and
cold rolling and cold annealing the hot-rolled steel sheet,
wherein a Charpy impact energy at -196°C is 120 J or more:

$$\text{Formula (1): } 70 \leq (100 - ASP) / (Ni / Mn) \leq 170$$

(wherein ASP represents austenite phase stability, ASP is calculated by 551-462(C+N)-9.2Si-8.1Mn-13.7Cr-29(Ni+Cu)-18.5Mo, and Ni and Mn represent wt% of the respective elements).

6. The method according to claim 5, wherein the austenitic stainless steel satisfies Formula (2) below:

$$\text{Formula (2): } 1.45Mn + 10Ni - 9.5Cu - 175N + 0.32(CVN@25°C) \geq 120$$

(wherein Mn, Ni, Cu, and N represent wt% of the respective elements, and CVN@25°C refers to a Charpy impact energy value at 25°C).

7. The method according to claim 5, wherein the austenitic stainless steel satisfies Formula (3) below and has a yield strength of 300 MPa or more:

$$\text{Formula (3): } 4.4 + 23(C + N)+1.3Si+0.24(Cr + Ni + Mn) \geq 16$$

(wherein C, N, Si, Cr, Ni, and Mn represent wt% of the respective elements).

8. The method according to claim 5, wherein the heating and extracting of the slab is performed at 1080 to 1280°C.

9. The method according to claim 5, wherein the hot rolling is performed at 800°C or above at a reduction ratio of 70% or more.

10. The method according to claim 5, wherein the hot annealing is performed at 1000 to 1200°C for 60 minutes or less.

11. The method according to claim 5, further comprising a cooling process after the hot rolling and before the hot annealing,

wherein the cooling process is performed at a cooling rate of 50°C/s or less.

12. The method according to claim 5, wherein the cold rolling is performed at room temperature at a reduction ratio of 50% or more.

13. The method according to claim 5, wherein the cold annealing is performed at 1000 to 1200°C for 10 minutes or less.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2023/006957

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/58(2006.01)i; **C22C 38/42**(2006.01)i; **C22C 38/44**(2006.01)i; **C21D 8/02**(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/58(2006.01); C21D 1/76(2006.01); C21D 8/02(2006.01); C22C 38/00(2006.01); C22C 38/02(2006.01); C22C 38/04(2006.01); C22C 38/60(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(austenitic), 저온(low temperature), 충격인성(impact toughness), 망간(manganese), 니켈(nickel)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 10-2022-0071006 A (POSCO) 31 May 2022 (2022-05-31) See paragraphs [0069] and [0073] and claims 1-6.	1-13
A	JP 2017-008413 A (NIPPON STEEL & SUMITOMO METAL) 12 January 2017 (2017-01-12) See paragraph [0058] and claims 1-4.	1-13
A	KR 10-2020-0045907 A (POSCO) 06 May 2020 (2020-05-06) See paragraph [0065] and claims 1, 3 and 5.	1-13
A	KR 10-2017-0107067 A (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORPORATION) 22 September 2017 (2017-09-22) See paragraph [0102] and claims 1-2 and 5.	1-13
A	CN 112877589 A (BAOSHAN IRON & STEEL CO., LTD.) 01 June 2021 (2021-06-01) See claims 1 and 6.	1-13

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 August 2023	**30 August 2023**

Name and mailing address of the ISA/KR	Authorized officer
Korean Intellectual Property Office **Government Complex-Daejeon Building 4, 189 Cheongsa-ro, Seo-gu, Daejeon 35208**	
Facsimile No. **+82-42-481-8578**	Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2023/006957

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