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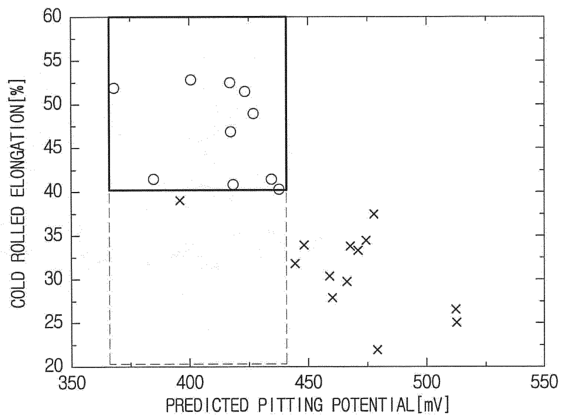
(54) **LEAN DUPLEX STAINLESS STEEL HAVING IMPROVED CORROSION RESISTANCE AND MACHINABILITY, AND MANUFACTURING METHOD THEREFOR**

(57) A lean duplex stainless steel and a method of manufacturing the same are provided. The lean duplex stainless steel includes, in percent (%) by weight of the entire composition, 0.08% or less of carbon (C) (excluding 0), 0.7 to 1.1% of silicon (Si), 2.4 to 3.5% of manganese (Mn), 17.9 to 20.7% of chromium (Cr), 0.05 to 1.15% of nickel (Ni), 0.18 to 0.3% of nitrogen (N), 0.4 to 2.8% of copper (Cu), and the remainder of iron (Fe) and inevitable impurities, wherein a predicted pitting potential is from 360 to 440 mV. Thus, manufacturing costs may be reduced via adjustment of components of the duplex stainless steel and both of formability and corrosion resistance may be improved by improving corrosion resistance and increasing elongation. Formability may be improved by inhibiting formation of thermal martensite and increasing elongation via adjustment of cooling conditions during coiling and cooling after hot rolling.

【FIG. 1】



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Description

[Technical Field]

[0001] The present disclosure relates to a lean duplex stainless steel and a method of manufacturing the same, and more particularly, to a lean duplex stainless steel manufactured with low costs by adjusting amounts of high-priced alloying components and having excellent corrosion resistance equal to or greater than those of STS 304 steels and excellent formability by inhibiting formation of thermal martensite via adjustment of cooling conditions during coiling and cooling after hot rolling and by increasing elongation via adjustment of a phase ratio and a method of manufacturing the lean duplex stainless steel.

[Background Art]

[0002] In general, austenitic stainless steels having excellent formability and corrosion resistance include iron (Fe), as a base metal, chromium (Cr) and nickel (Ni), as major raw materials, and other elements such as molybdenum (Mo) and copper (Cu) and have been developed to a variety of steel types suitable for various applications.

[0003] Austenitic stainless steels, a type of steels having excellent corrosion resistance and pitting corrosion resistance, include a low content of carbon (C) and at least 8% of nickel (Ni). Accordingly, an increase in price of nickel (Ni) causes a wide range of fluctuation in price of raw materials, and thus unstable price may result in low price competitiveness. Thus, in order to compensate for this, there is a need to develop a new steel type having corrosion resistance equal to or higher than those of austenitic stainless steels while reducing the content of nickel (Ni).

[0004] Accordingly, a duplex stainless steel, which is a stainless steel having a fine structure consisting of a mixture of an austenite phase and a ferrite phase, has properties of both austenitic and ferritic steels. A variety of duplex stainless steels, such as, a stainless steel disclosed in US Patent No. 6096441 (registered on August 1, 2000), have been suggested.

[0005] US Patent No. 6096441 (registered on August 1, 2000) discloses "austenoferritic stainless steel having a low nickel content and a high tensile elongation". This steel includes iron, as a base metal, and the following elements in amounts indicated by weight based on a total weight: carbon (C)<0.04%, 0.4%<silicon (Si)<1.2%, 2%<manganese (Mn)<4%, 0.1%<nickel (Ni)<1.0%, 18%<chromium (Cr)<22%, 0.05%<copper (Cu)<4.0%, sulfur (S)<0.03%, phosphorus (P)<0.1%, 0.1%<nitrogen (N)<0.3%, molybdenum (Mo)<3.0%, and impurities, the steel having a two-phase structure of 30% to 70% of austenite and ferrite, where Creq=Cr(%)+Mo(%)+1.5Si(%), Nieq=Ni(%)+0.33Cu(%)+0.5Mn(%)+30C(%)+30N(%) with Creq/Nieq between 2.3 and 2.75, the stability of austenite of the steel being controlled by the IM index defined, based on the weight composition of the steel, by IM=551-805(C+N)(%)-8.52Si(%)-8.57Mn(%)-12.51Cr(%)-36Ni(%)-34.5Cu(%)-14Mo(%), IM being between 40 and 115.

[0006] The duplex stainless steel provides excellent corrosion resistance to various corrosion environments and has better corrosion resistance than AISI 304 and AISI 316 austenite stainless steels. In the case of such duplex stainless steels, not only manufacturing costs increase due to high-priced elements such as nickel (Ni) and molybdenum (Mo), but also price competitiveness decreases in comparison with other steel types due to consumption of nickel (Ni), molybdenum (Mo), and the like.

[0007] Accordingly, in recent years, among duplex stainless steels, lean duplex stainless steels including low-priced alloy elements that replace the high-priced alloy elements such as nickel (Ni) and molybdenum (Mo) have drawn a great deal of attention and interest to reduce the manufacturing costs.

[0008] Lean duplex stainless steels are economical and easy to obtain high strength due to corrosion resistance equal to that of AISI 304 and 316 steels which are conventional austenitic stainless steels and a low Ni content so as to be currently in the spotlight as steel materials for industrial facilities requiring corrosion resistance such as desalination facilities, pulp facilities, paper manufacturing facilities, and chemical facilities.

[0009] Such lean duplex steels are, for example, S32304 stainless steel standardized in ASTM A240 (main component: 23Cr-4Ni-0.13N) and S32101 stainless steel standardized in ASTM A240 (main component: 21Cr-1.5Ni-5Mn-0.22N).

[0010] These duplex stainless steels are designed to enhance corrosion resistance rather than cold processibilty, i.e., formability, to provide superior corrosion resistance to corrosion resistance required in certain applications. In addition, although stress corrosion resistance is also better than design requirements to provide a technical solution, ductility, a factor related to formability, is lower than that of austenitic stainless steels. As a result, many restrictions are caused in various industrial fields requiring molding, bending, and the like, deteriorating economic validity.

[0011] Thus, there is a need to develop duplex stainless steels suitable for industrial equipment and various molding processes requiring corrosion resistance equal to or higher than those of AISI 304, 304L, and 316 steels, and particularly, formability, i.e., ductility, equal to that of AISI 304 steel manufactured with reduced manufacturing costs by replacing the high-priced elements.

[0012] In addition, since austenitic stainless steels generally having excellent formability, i.e., high elongation, include

4% or more of high-priced Ni, manufacturing costs thereof increase and a valuable natural resource of Ni is consumed in a large amount.

[0013] In addition, although a large amount of Mn considerably increases a solid solubility of nitrogen to obtain high corrosion resistance of lean duplex stainless steels, inclusions impairing corrosion resistance, such as MnS, are easily formed thereby, resulting in deterioration of corrosion resistance. Also, environmental problems may be caused by Mn dusts generated during operation using an electric furnace. Therefore, there is a two-phase structure steel in which a ferrite phase and an austenite phase are co-exist to obtain elongation and corrosion resistance equal to those of austenitic steels has been developed with reduced contents of Ni, Mn, and the like.

[0014] (Patent Document 0001) US Patent No. 6096441 (registered on August 1, 2000)

[Disclosure]

[Technical Problem]

[0015] The present disclosure is directed to providing a lean duplex stainless steel having excellent corrosion resistance and excellent formability by increasing elongation and manufactured with reduced costs via adjustment of components of the duplex stainless steel.

[0016] Further, the present disclosure is directed to providing a method of manufacturing a lean duplex stainless steel having excellent formability by inhibiting formation of thermal martensite and by increasing elongation via adjustment of cooling conditions during coiling and cooling after hot rolling.

[Technical Solution]

[0017] One aspect of the present disclosure provides a lean duplex stainless steel having excellent corrosion resistance and formability and including, in percent (%) by weight of the entire composition, 0.08% or less of carbon (C) (excluding 0), 0.7 to 1.1% of silicon (Si), 2.4 to 3.5% of manganese (Mn), 17.9 to 20.7% of chromium (Cr), 0.05 to 1.15% of nickel (Ni), 0.18 to 0.3% of nitrogen (N), 0.4 to 2.8% of copper (Cu), and the remainder of iron (Fe) and inevitable impurities, wherein a predicted pitting potential obtained by Equation (1) below is from 360 to 440 mV.

$$\text{Pitting potential} = -623.2 + 47.4Cr_{eq} \text{ ...... Equation (1)}$$

$$(Cr_{eq} = Cr + 1.37Mo + 0.75W + 1.5Si + 2Nb + 3Ti + 5V + 5.5Al)$$

[0018] Also, according to an embodiment, the stainless steel may further include at least one selected from the group consisting of 1.0% or less of molybdenum (Mo) and 1.0% or less of tungsten (W) and a total content of molybdenum (Mo) and tungsten (W) may be from 0.15 to 1.0%.

[0019] Also, according to an embodiment, the stainless steel may further include at least one selected from the group consisting of 0.05% or less of titanium (Ti), 0.09% or less of niobium (Nb), 0.095% or less of vanadium (V), and 0.19% or less of tin (Sn).

[0020] Also, according to an embodiment, the stainless steel may further include at least one selected from the group consisting of 0.19% of tin (Sn) and 0.1% of antimony (Sb).

[0021] Also, according to an embodiment, the stainless steel may include 40 to 75% of an austenite phase and the remainder of a ferrite phase.

[0022] Also, according to an embodiment, the stainless steel may have a fraction of thermal martensite of 10% or less.

[0023] In addition, the stainless steel may have a pitting potential of 360 mV or higher.

[0024] Also, according to an embodiment, the stainless steel may have a hot-rolled elongation of 35% or more.

[0025] Also, according to an embodiment, the stainless steel may have a cold-rolled elongation of 40% or more.

[0026] Another aspect of the present disclosure provides a method of manufacturing a lean duplex stainless steel having excellent corrosion resistance and formability including preparing a lean duplex stainless steel slab including, in percent (%) by weight of the entire composition, 0.08% or less of carbon (C) (excluding 0), 0.7 to 1.1% of silicon (Si), 2.4 to 3.5% of manganese (Mn), 17.9 to 20.7% of chromium (Cr), 0.05 to 1.15% of nickel (Ni), 0.18 to 0.3% of nitrogen (N), 0.4 to 2.8% of copper (Cu), and the remainder of iron (Fe) and inevitable impurities, and hot rolling, hot annealing, coiling, cooling, cold rolling, and cold annealing the slab, wherein the stainless steel has a predicted pitting potential of 360 to 440 mV obtained by Equation (1) below.

$$\text{Pitting potential} = -623.2 + 47.4Cr_{eq} \text{ ...... Equation (1)}$$

$$(Cr_{eq} = Cr + 1.37Mo + 0.75W + 1.5Si + 2Nb + 3Ti + 5V + 5.5Al)$$

[0027] Also, according to an embodiment, a coiling temperature of a hot annealed steel and a cooling speed after coiling satisfy Equation (3) below.

$$A \leq 690 + 25*\log B \text{ ...... Equation (3)}$$

[0028] In this case, A is coiling temperature (°C) and B is cooling speed after coiling (°C/sec).

[Advantageous Effects]

[0029] According to embodiments of the present disclosure, manufacturing costs may be reduced in comparison with austenitic stainless steels by adjusting the content of an alloy component such as Ni, Si, Mn, and Cu among components of the duplex stainless steel, and both of formability and corrosion resistance of the duplex stainless steel may be improved by increasing an elongation of a hot annealed steel to 35% or more and an elongation of a cold annealed steel to 40% or more via adjustment of phase fractions of ferrite and austenite phases and via addition of Mo, W, rare earth elements, and the like to improve corrosion resistance equal to or higher than that of STS 304 steels.

[0030] In addition, according to the embodiments of the present disclosure, formability may be improved by inhibiting formation of thermal martensite via adjustment of cooling conditions during coiling and cooling after hot rolling and by increasing elongation via adjustment of phase fractions of ferrite and austenite phases.

[Description of Drawings]

[0031]

FIG. 1 is a graph for describing a correlation between predicted pitting potentials and cold rolled elongations of cold annealed duplex stainless steels manufactured according to examples of the present disclosure and comparative examples.

FIG. 2 is a photograph illustrating a microstructure of a hot annealed steel manufactured according to Comparative Example 11 including thermal martensite.

FIG. 3 is a graph illustrating stress-strain curves of hot annealed duplex stainless steels manufactured according to Example 3 of the present disclosure and Comparative Example 11.

FIG. 4 is a graph for describing a correlation between fractions of thermal martensite and hot rolled elongations of hot annealed duplex stainless steels manufactured according to examples of the present disclosure and comparative examples.

FIG. 5 is a graph for describing formation of thermal martensite in hot annealed duplex stainless steels according to coiling temperature and cooling speed after coiling.

[Best Mode]

[0032] A lean duplex stainless steel having excellent corrosion resistance and formability according to an embodiment includes, in percent (%) by weight of the entire composition, 0.08% or less of carbon (C) (excluding 0), 0.7 to 1.1% of silicon (Si), 2.4 to 3.5% of manganese (Mn), 17.9 to 20.7% of chromium (Cr), 0.05 to 1.15% of nickel (Ni), 0.18 to 0.3% of nitrogen (N), 0.4 to 2.8% of copper (Cu), and the remainder of iron (Fe) and inevitable impurities, wherein a predicted pitting potential obtained by Equation (1) below is from 360 to 440 mV.

$$\text{Pitting potential} = -623.2 + 47.4Cr_{eq} \text{ ...... Equation (1)}$$

$$(Cr_{eq} = Cr + 1.37Mo + 0.75W + 1.5Si + 2Nb + 3Ti + 5V + 5.5Al)$$

[Modes of the Invention]

[0033] Hereinafter, embodiments of the present disclosure will be described in detail with reference to the accompanying drawings. These embodiments are provided to fully convey the concept of the present disclosure to those of ordinary skill in the art. The present disclosure may, however, be embodied in many different forms and should not be construed as limited to the exemplary embodiments set forth herein. In the drawings, parts unrelated to the descriptions are omitted for clear description of the disclosure and sizes of elements may be exaggerated for clarity.

[0034] A lean duplex stainless steel having excellent corrosion resistance and formability according to an embodiment includes, in percent (%) by weight of the entire composition, 0.08% or less of carbon (C) (excluding 0), 0.7 to 1.1% of silicon (Si), 2.4 to 3.5% of manganese (Mn), 17.9 to 20.7% of chromium (Cr), 0.05 to 1.15% of nickel (Ni), 0.18 to 0.3% of nitrogen (N), 0.4 to 2.8% of copper (Cu), and the remainder of iron (Fe) and inevitable impurities.

[0035] The content of C is 0.08% or less (excluding 0).

[0036] C is an austenite-forming element and an effective element for increasing strength of a material by solid solution hardening. However, since excess C atoms easily bind to carbide-forming element such as Cr, which is effective for corrosion resistance, at an interface between ferrite and austenite phases resulting in a decrease in the Cr content around crystal grains thereby deteriorating corrosion resistance, the C content may be greater than 0% and equal to or less than 0.08% to maximize corrosion resistance.

[0037] The Si convent is from 0.7 to 1.1%.

[0038] Si is added in a small amount for deoxidation effects and a ferrite-forming element enriched in ferrite by annealing. Thus, the Si content needs to be 0.7% or more to obtain a proper fraction of a ferrite phase. However, the Si content exceeding 1.1% rapidly increases hardness resulting in a decrease in elongation of the duplex stainless steel and makes it difficult to obtain the austenite phase for sufficient elongation. In addition, excess Si atoms lower fluidity of a slag during a steelmaking process and bind to oxygen atoms to form inclusions thereby impairing corrosion resistance. Thus, the Si content may be from 0.7% or more to 1.1% or less.

[0039] The Mn content is from 2.4 to 3.5%.

[0040] Mn, as a deoxidizer and an element increasing a solid solubility of nitrogen, is an austenite-forming element and used to replace the high-priced Ni. When the Mn content exceeds 3.5%, it is difficult to obtain corrosion resistance at a level similar to that of STS 304 steel. This is because excess Mn atoms may form MnS with S atoms contained in steels thereby impairing corrosion resistance, although Mn may increase the solid solubility of N. In addition, when the Mn content is less than 2%, it is difficult to obtain a proper faction of the austenite phase even by adjusting the contents of Ni, Cu, N, and the like which are austenite-forming elements and it is also difficult to obtain a sufficient solid solubility of N at an atmospheric pressure due to a low solid solubility of N added thereto. Thus, the Mn content may be from 2.4% or more to 3.5% or less.

[0041] The Cr content is from 17.9 to 20.7%.

[0042] Cr, as a ferrite-stabilizing element together with Si, not only plays an important role in obtaining the ferrite phase of the duplex stainless steel but also is an essential element to obtain corrosion resistance. Although an increase in the Cr content improves corrosion resistance, the contents of the austenite-forming elements such as the high-priced Ni also need to be increased to maintain a phase ratio. Thus, manufacturing costs may be increased. Thus, the Cr content may be from 17.9% or more to 20.7% or less to obtain corrosion resistance at a level similar to that of STS 304 steel while maintaining a phase ratio of the duplex stainless steel.

[0043] The Ni content is from 0.05 to 1.15%.

[0044] Ni, as an austenite-stabilizing element together with Mn, Cu and N, plays a main role in obtaining the austenite phase of the duplex stainless steel. The balance of the fractions of the phases may be maintained by increasing the contents of Mn and N, which are austenite-forming elements replacing the high-priced Ni, in order to reduce manufacturing costs. However, the Ni content may be 0.05% or more to obtain sufficient stabilization of austenite to inhibit formation of strain induced martensite during cold rolling. However, excess Ni makes it difficult to obtain a proper fraction of austenite due to an increases in the fraction of austenite and particularly lowers price competitiveness to STS 304 steel due to an increase in manufacturing costs by using the high-priced Ni. Thus, the Ni content may be from 0.05% or more to 1.15% or less.

[0045] The N content is from 0.18 to 0.3%.

[0046] N, as an element playing an important role in stabilizing the austenite phase of the duplex stainless steel together with Ni, is enriched in the austenite phase by an annealing process. Thus, the increase of the N content may additionally improve corrosion resistance and increase strength. However, the solid solubility of N may vary in accordance with the content of added Mn. When the N content exceeds 0.3% in the case where the Mn content is within the range described above, steels may not be stably manufactured due to surface defects caused by formation of blow holes and pin holes during a steelmaking process due to excessive solid solubility of N. Meanwhile, the N content may be 0.2% or more to obtain corrosion resistance at a level similar to that of STS 304 steel. When the N content is too low, it is difficult to obtain proper phase fractions. Thus, the N content may be from 0.18% or more to 0.30% or less.

[0047] The Cu content may be from 0.4 to 2.8%.

[0048] Cu, as an austenite-forming element, is an element for the balance of the phase fractions and for replacing Ni. Cu is an element having the same effects as Ni. When a ferrite-forming element improving corrosion resistance is added, the Cu content needs to be 0.4% or more in the case where the Ni content is within the range described above to obtain sufficient ductility, i.e., to generate strain induced martensite or mechanical twining during a cold rolling process. In addition, since excess Cu may cause brittleness during a hot rolling process, the Cu content may be 2.8% or less in consideration of an amount to be solidified. Thus, the Cu content may be from 0.4% or more to 2.8% or less.

[0049] The lean duplex stainless steel having excellent corrosion resistance and formability according to an embodiment may further include at least one selected from the group consisting of 1.0% or less of molybdenum (Mo) and 1.0% or less of tungsten (W).

[0050] Mo and W, as ferrite-forming elements, improve corrosion resistance and are mostly distributed in the ferrite phase. Particularly, W is an element added in place of Mo. In addition, the above-described alloying components promote formation of intermetallic compounds at a temperature of 600 to 1,000°C during heat treatment, resulting in impairing of corrosion resistance and mechanical properties.

[0051] In the case of Mo, more than 0% may be added to obtain the effect on improving corrosion resistance. However, when the Mo content exceeds 1.0%, intermetallic compounds are formed, resulting in rapid deterioration of corrosion resistance, particularly, elongation.

[0052] Therefore, the Mo content may be greater than 0% to 1.0% or less.

[0053] In the case of W, more than 0% may be added to obtain the effect on improving corrosion resistance. However, when the W content exceeds 1.0%, intermetallic compounds are formed, resulting in rapid deterioration of corrosion resistance, particularly, elongation.

[0054] Therefore, the W content may be greater than 0% to 1.0% or less.

[0055] The lean duplex stainless steel having excellent corrosion resistance and formability according to an embodiment may have a total content of molybdenum (Mo) and tungsten (W) of 0.15 to 1.0% to obtain elongation and corrosion resistance of hot rolled and cold rolled materials.

[0056] When Mo, W, and the like, which are elements generally used to improve corrosion resistance, are added, corrosion resistance is improved while elongation is rapidly decreased due to a considerable enhancement of the stability of austenite, since most of these elements are ferrite-forming elements. As a result of examining a correlation between Mo and W, which are main alloying components affecting corrosion resistance, and elongation, the total of Mo and W may be from 0.15 to 1.0% to obtain excellent corrosion resistance and elongation.

[0057] The lean duplex stainless steel having excellent corrosion resistance and formability according to an embodiment may further include at least one selected from the group consisting of 0.05% or less of titanium (Ti), 0.09% or less of niobium (Nb), 0.095% or less of vanadium (V), and 0.19% or less of tin (Sn).

[0058] Ti, Nb, and V serve as deoxidizers, bind to oxygen to form inclusions during a steelmaking process and a casting process, and react with C or N to form carbides or carbonitrides while coiling and cooling after a hot rolling process or while hot annealing and cold annealing. These precipitates inhibit formation of Cr carbides and inhibit formation of thermal martensite while cooling, thereby contributing improvement of elongation in a hot rolled state.

[0059] Thus, the Ti content may be more than 0% to 0.05% or less, the Nb content may be more than 0% to 0.09% or less, and the V content may be more than 0% to 0.095% or less.

[0060] The lean duplex stainless steel having excellent corrosion resistance and formability according to an embodiment may further include at least one selected from the group consisting of 0.19% or less of tin (Sn) and 0.1% of antimony (Sb).

[0061] Sn is known as an element that is enriched on the surface during an annealing process to improve corrosion resistance of an alloy. To obtain the effect of addition of Sn, more than 0% of Sn needs to be added. Sn is a ferrite phase-forming element and causes brittleness during a hot rolling process. While brittleness is caused during the hot rolling process when Sn is added in an amount more than 0.19%, the effect on forming the ferrite phase is not affected when Sn is added in an amount more than 0.19%. Thus, the Sn content may be more than 0% to 0.19% or less.

[0062] Sb is known as an element that is enriched on the surface during an annealing process to improve corrosion resistance of an alloy. To obtain the effect of addition of Sb, more than 0% of Sn needs to be added. When Sb is added in an amount more than 0.1%, brittleness may be caused during a hot rolling process. Thus, the Sb content may be from more than 0% to 0.1% or less.

[0063] FIG. 1 is a graph for describing a correlation between predicted pitting potentials and cold rolled elongations of cold annealed duplex stainless steels manufactured according to examples of the present disclosure and comparative examples.

[0064] Referring to FIG. 1, the lean duplex stainless steel having excellent corrosion resistance and formability according to an embodiment has a predicted pitting potential of 360 to 440 mV which is obtained by Equation (1) below.

$$\text{Pitting potential} = -623.2 + 47.4\text{Creq} \ \ldots\ldots \ \text{Equation (1)}$$

$$(\text{Creq} = \text{Cr} + 1.37\text{Mo} + 0.75\text{W} + 1.5\text{Si} + 2\text{Nb} + 3\text{Ti} + 5\text{V} + 5.5\text{Al})$$

[0065] When the pitting potential predicted by Equation (1) above exceeds 440 mV, a cold rolled elongation is less than 40%.

[0066] In this regard, Creq = Cr + 1.37Mo + 0.75W + 1.5Si + 2Nb + 3Ti + 5V + 5.5A1. While pitting potential of a material increases by adding elements capable of improving corrosion resistance such as Mo and W, elongation may decrease by adding these elements.

[0067] That is, improvement of corrosion resistance by adding alloying components may cause deterioration of formability. As a result of examining a correlation between pitting potential and elongation, when the pitting potential predicted by Equation (1) above is in the range of 360 to 440 mV, elongation of a cold annealed steel may be 40% or more.

[0068] Thus, the pitting potential of the stainless steel may be 360 mV or more. Accordingly, the lean duplex stainless steel according to an embodiment may have corrosion resistance equal to or better than those of STS 304 steels.

[0069] For example, the stainless steel may include, in a volume fraction, 40 to 75% of an austenite phase and the remainder of a ferrite phase.

[0070] When the volume fraction of the austenite phase is less than 40%, austenite-forming elements are excessively enriched in the austenite phase during an annealing process. Thus, austenite is sufficiently stabilized to suppress an amount of modified organic martensite transformation that occurs during deformation and tensile strength of the material may be sufficiently obtained due to excessive increase in strength of austenite due to excessive solidification of alloying elements. However, since ductility decreases, desired elongation and strength cannot be sufficiently obtained. Thus, the fraction of austenite may be 40% or more to improve ductility.

[0071] In addition, when the fraction of austenite exceeds 75%, surface cracking occurs during hot rolling, thereby deteriorating hot rolling formability, and thus properties of two-phase steel may be lost. In addition, since the ferrite phase is rapidly strengthened by accumulation of the ferrite phase-forming elements, yield strength is increased to destruct the ferrite phase, resulting in a rapid decrease in ductility of the stainless steel. Thus, the fraction of austenite may be 75% or less.

[0072] Thus, a preferable fraction of the austenite phase to obtain a proper elongation of a hot annealed duplex stainless steel or a cold annealed steel, i.e., an elongation as a result of formation of strain induced martensite from austenite, may be from 40 to 75%. Thus, the remainder of the stainless steel includes the ferrite phase, that is, the fraction of the ferrite phase may be from 25 to 60%.

[0073] For example, the fraction of thermal martensite may be 10% or less in the stainless steel.

[0074] FIG. 2 is a photograph illustrating a microstructure of a hot annealed steel manufactured according to Comparative Example 11 including thermal martensite. FIG. 3 is a graph illustrating stress-strain curves of hot annealed duplex stainless steels manufactured according to Example 3 of the present disclosure and Comparative Example 11. FIG. 4 is a graph for describing a correlation between fractions of thermal martensite and hot rolled elongations of hot annealed duplex stainless steels manufactured according to examples of the present disclosure and comparative examples.

[0075] Referring to FIG. 2, the microstructure of the duplex stainless steel including thermal martensite according to a comparative example is illustrated.

[0076] FIG. 2 is a photograph illustrating a microstructure of a hot annealed steel manufactured according to Comparative Example 11 including thermal martensite. In FIG. 2, dark brown indicates ferrite phase 1, gray indicates austenite phase 2, and relatively light brown shown as needles indicates thermal martensite 3 formed while cooling.

[0077] Stress-strain curves of a steel according to Comparative Example 11 in which a large amount of thermal martensite is observed and a steel according to Example 3 in which little thermal martensite is observed are shown in FIG. 3. Referring to FIG. 3, it may be confirmed that the of Example 3 according to an embodiment of the present disclosure has a higher strain rate of a hot annealed steel than that of Comparative Example 11. That is, when thermal martensite is present, a steel may have a relatively low strain rate, i.e., an elongation of 30% or less, in comparison with a steel normally coiled and not including thermal martensite.

[0078] Referring to FIG. 4, as shown in the correlation between fractions of thermal martensite and hot rolled elongations, when the fraction of thermal martensite exceeds 10%, it is confirmed that the hot rolled elongation is less than 35%.

[0079] That is, the lean duplex stainless steel according to an embodiment of the present disclosure has a hot rolled elongation of 35% or more and a cold rolled elongation of 40% or more.

[0080] As a result of examining difference between elongations of hot annealed steels and elongations of cold annealed steels, when a hot annealed steel having an elongation of 35% or more is cold rolled, it may be confirmed that the cold rolled steel has an elongation of 40% or more which is higher than those of lean duplex stainless steels commonly used in the art.

[0081] According to the method of manufacturing the lean duplex stainless steel having excellent corrosion resistance and formability according to an embodiment, a lean duplex stainless steel may be manufactured by preparing a lean duplex stainless steel slab having the composition and hot rolling, hot annealing, coiling, and cooling the slab.

[0082] In this regard, the coiling temperature of the hot annealed steel and the cooling speed after coiling satisfy Equation (3) below.

$$A \leq 690 + 25*\log B \ \ldots\ldots \text{ Equation (3)}$$

[0083] Here, A is coiling temperature (°C) and B is cooling speed after coiling (°C/sec).

[0084] As a result of examining a correlation between formation of thermal martensite and elongation of hot annealed steels according to coiling temperature after hot rolling or casting and, it was confirmed that the coiling temperature has a great influence on the elongation of the hot annealed steels. Also, when the elongation of the hot annealed steel is 35% or more, it was confirmed that the cold annealed steel after cold rolling had an elongation of 40% or more.

[0085] When duplex stainless steels are coiled and slowly cooled or heat-treated at a temperature of 600 to 900°C according to a conventional method, precipitates having a sigma phase and including Cr nitrides, Mo or W are formed in an interface between the ferrite phase and the austenite phase contained in the duplex stainless steel and grow to an austenite phase.

[0086] When these precipitates are formed, alloying components such as C, N, and Cr, which form solid solution in the austenite phase, around the precipitates are precipitated, and thus the austenite phase around the precipitates forms thermal martensite during cooling due to lack of alloying components.

[0087] When the thermal martensite is formed as described above, stability of austenite rapidly deteriorates and thus strain induced martensite is deformed at an early stage, thereby rapid decreasing in elongation of steels.

[0088] FIG. 5 is a graph for describing formation of thermal martensite in hot annealed duplex stainless steels according to coiling temperature and cooling speed after coiling.

[0089] Referring to FIG. 5, it may be confirmed that thermal martensite tends to be formed in the hot annealed steel according to the coiling temperature and cooling speed after coiling. That is, more than 10% of thermal martensite was observed in coiling temperature and cooling speed conditions shown as "X" in FIG. 5 and no thermal martensite or 10% or less of thermal martensite was observed in coiling temperature and cooling speed conditions shown as "O" in FIG. 5.

[0090] As a result of examining a correlation among coiling temperature of steels, cooling speed after coiling, and elongation, the hot annealed steel may have an elongation of 35% or more by inhibiting formation of thermal martensite via adjustment of the coiling temperature and cooling speed conditions to satisfy Equation (3) above.

[0091] Hereinafter, one or more embodiments of the present disclosure will be described in more detail with reference to the following examples and comparative examples.

Steels of Examples and Steels of Comparative Examples

[0092] Lean duplex stainless steel samples including components as shown in Tables 1 and 2 below were prepared according to the following examples and comparative examples. The samples were hot rolled, hot annealed, cold rolled, and cold annealed.

Table 1

(wt%)	C	Si	Mn	P	Cr	Ni	Mo	Ti
Steel of Example 1	0.037	0.720	2.530	0.000	20.000	0.780	0.100	0.000
Steel of Example 2	0.038	0.710	2.550	0.000	19.940	0.820	0.530	0.000
Steel of Example 3	0.039	0.710	2.850	0.000	19.930	0.800	0.510	0.001
Steel of Comparative Example 1	0.021	0.780	2.940	0.000	20.300	0.920	0.500	0.000
Steel of Comparative Example 2	0.019	0.800	2.850	0.000	20.300	0.920	0.490	0.060
Steel of Comparative Example 3	0.021	0.710	2.900	0.000	20.300	0.920	0.490	0.000
Steel of Comparative Example 4	0.026	1.150	2.800	0.000	19.950	0.920	0.580	0.000

(continued)

(wt%)	C	Si	Mn	P	Cr	Ni	Mo	Ti
Steel of Comparative Example 5	0.029	1.790	2.970	0.000	20.100	0.900	0.590	0.000
Steel of Comparative Example 6	0.033	1.820	2.940	0.000	20.000	0.910	0.630	0.000
Steel of Comparative Example 7	0.032	0.820	2.980	0.000	20.800	1.020	0.710	0.000
Steel of Comparative Example 8	0.032	0.830	3.050	0.000	20.400	1.030	0.710	0.000
Steel of Comparative Example 9	0.028	0.760	3.070	0.000	20.210	0.750	0.710	0.000
Steel of Comparative Example 10	0.029	1.050	2.970	0.000	20.340	1.000	0.700	0.000
Steel of Comparative Example 11	0.038	0.690	2.880	0.000	20.120	0.820	0.250	0.000
Steel of Comparative Example 12	0.082	0.950	3.060	0.000	20.000	0.104	1.210	0.000
Steel of Comparative Example 13	0.027	0.920	2.950	0.000	19.950	1.190	1.230	0.000
Steel of Comparative Example 14	0.084	0.940	3.100	0.000	15.090	0.100	1.200	0.000

Table 2

	Nb	Cu	V	N	W	Ca	Sn	Sb
Steel of Example 1	0.005	0.790	0.000	0.250	0.050	0.000	0.000	0.000
Steel of Example 2	0.000	0.800	0.000	0.240	0.300	0.000	0.000	0.000
Steel of Example 3	0.001	0.780	0.000	0.244	0.330	0.000	0.000	0.000
Steel of Comparative Example 1	0.000	0.500	0.000	0.223	0.490	0.000	0.200	0.000
Steel of Comparative Example 2	0.000	0.520	0.100	0.228	0.500	0.000	0.200	0.000
Steel of Comparative Example 3	0.097	0.810	0.000	0.251	0.500	0.004	0.200	0.000
Steel of Comparative Example 4	0.000	0.900	0.000	0.076	0.480	0.000	0.000	0.000
Steel of Comparative Example 5	0.000	0.910	0.000	0.075	0.480	0.000	0.000	0.000
Steel of Comparative Example 6	0.000	1.760	0.000	0.087	0.490	0.000	0.126	0.000
Steel of Comparative Example 7	0.000	1.730	0.000	0.190	0.200	0.000	0.000	0.050
Steel of Comparative Example 8	0.000	1.690	0.000	0.230	0.490	0.000	0.000	0.120
Steel of Comparative Example 9	0.000	1.840	0.000	0.233	0.710	0.000	0.000	0.000
Steel of Comparative Example 10	0.000	1.760	0.000	0.239	0.510	0.000	0.000	0.000
Steel of Comparative Example 11	0.000	0.810	0.000	0.220	0.000	0.000	0.000	0.000
Steel of Comparative Example 12	0.000	2.550	0.000	0.230	0.000	0.000	0.000	0.000
Steel of Comparative Example 13	0.000	1.400	0.000	0.167	0.000	0.000	0.000	0.000
Steel of Comparative Example 14	0.000	2.610	0.000	0.163	0.000	0.000	0.000	0.000

[0093] Then, the steels of Examples and the steels of Comparative Examples were cold rolled, and phase ratios and elongations, and predicted pitting potentials obtained by Equation (1) above are shown in Table 3 below.

Table 3

	Fraction of ferrite (%)	Elongation (%)	Predicted pitting potential
Steel of Example 1	43.00	41.50	384.86
Steel of Example 2	46.00	46.90	417.63
Steel of Example 3	49.00	52.50	417.16

(continued)

	Fraction of ferrite (%)	Elongation (%)	Predicted pitting potential
Steel of Comparative Example 1	48.35	31.80	444.48
Steel of Comparative Example 2	54.10	37.50	477.84
Steel of Comparative Example 3	45.52	33.90	448.40
Steel of Comparative Example 4	77.97	30.30	459.04
Steel of Comparative Example 5	77.90	26.50	512.30
Steel of Comparative Example 6	76.78	25.00	512.65
Steel of Comparative Example 7	52.79	34.40	474.35
Steel of Comparative Example 8	52.79	29.70	466.41
Steel of Comparative Example 9	45.03	27.90	460.25
Steel of Comparative Example 10	42.41	21.90	479.27
Steel of Comparative Example 11	41.00	39.00	395.89
Steel of Comparative Example 12	38.51	33.30	471.03
Steel of Comparative Example 13	48.63	33.80	467.83
Steel of Comparative Example 14	53.00	33.00	236.92

[0094] In this regard, the elongations were obtained by collecting the samples in a direction perpendicular to a rolling direction, i.e., a width direction, and performing measurement at a strain rate of $6.6x10^{-3}$/s.

[0095] FIG. 1 is a graph for describing the correlation between predicted pitting potentials and cold rolled elongations of cold annealed duplex stainless steels manufactured according to examples of the present disclosure and comparative examples. FIG. 1 illustrates elongations and predicted pitting potentials of the steels of Examples and the steels of Comparative Examples shown in Table 3 as a graph. Referring to FIG. 1, as the predicted pitting potential increases, the elongation decreases. To obtain the elongation of the cold annealed steel of 40% or more in the width direction of the cold annealed steel, it may be confirmed that the predicted pitting potential needs to be within the range of 360 to 440 mmV.

[0096] According to the embodiments of the present disclosure, manufacturing costs may be reduced by adjusting the contents of the alloying components such as Ni, Si, Mn, and Cu among components of the duplex stainless steel in comparison with austenitic stainless steels, and both of formability and corrosion resistance of the duplex stainless steel may be improved by increasing an elongation of the hot annealed steel to 35% or more and an elongation of the cold annealed steel to 40% or more via adjustment of the factions of ferrite and austenite and by improving corrosion resistance to a level equal to or greater than those of STS 304 steels via addition of Mo, W, rare earth elements, and the like. In addition, formability may be improved by obtaining a proper elongation by suppressing formation of thermal martensite via adjustment of cooling conditions during coiling and cooling after hot rolling.

[0097] 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 Availability]

[0098] The lean duplex stainless steel according to embodiments of the present disclosure may be industrially applicable as steel materials for industrial facilities such as desalination facilities, pulp facilities, paper manufacturing facilities, and chemical facilities.

Claims

1. A lean duplex stainless steel having improved corrosion resistance and formability comprising, in percent (%) by weight of the entire composition, 0.08% or less of carbon (C) (excluding 0), 0.7 to 1.1% of silicon (Si), 2.4 to 3.5% of manganese (Mn), 17.9 to 20.7% of chromium (Cr), 0.05 to 1.15% of nickel (Ni), 0.18 to 0.3% of nitrogen (N), 0.4

to 2.8% of copper (Cu), and the remainder of iron (Fe) and inevitable impurities, wherein a predicted pitting potential obtained by Equation (1) below is from 360 to 440 mV:

$$\text{Pitting potential} = -623.2 + 47.4Cr_{eq} \text{ ...... Equation (1)}$$

$$(Cr_{eq} = Cr + 1.37Mo + 0.75W + 1.5Si + 2Nb + 3Ti + 5V + 5.5Al).$$

2. The lean duplex stainless steel of claim 1, further comprising at least one selected from the group consisting of 1.0% or less of molybdenum (Mo) and 1.0% or less of tungsten (W),
wherein a total content of the molybdenum (Mo) and the tungsten (W) is from 0.15 to 1.0%.

3. The lean duplex stainless steel of claim 1, further comprising at least one selected from the group consisting of 0.05% or less of titanium (Ti), 0.09% or less of niobium (Nb), 0.095% or less of vanadium (V), and 0.19% or less of tin (Sn).

4. The lean duplex stainless steel of claim 1, further comprising at least one selected from the group consisting of 0.19% or less of tin (Sn) and 0.1% of antimony (Sb).

5. The lean duplex stainless steel of claim 1, wherein the stainless steel comprises 40 to 75% of an austenite phase and the remainder of a ferrite phase.

6. The lean duplex stainless steel of claim 5, wherein the stainless steel has a fraction of thermal martensite of 10% or less.

7. The lean duplex stainless steel of claim 1, wherein the stainless steel has a pitting potential of 360 mV or more.

8. The lean duplex stainless steel of claim 1, wherein the stainless steel has a hot rolled elongation of 35% or more.

9. The lean duplex stainless steel of claim 1, wherein the stainless steel has a cold rolled elongation of 40% or more.

10. A method of manufacturing a lean duplex stainless steel having improved corrosion resistance and formability, the method comprising:

preparing a lean duplex stainless steel slab comprising, in percent (%) by weight of the entire composition, 0.08% or less of carbon (C) (excluding 0), 0.7 to 1.1% of silicon (Si), 2.4 to 3.5% of manganese (Mn), 17.9 to 20.7% of chromium (Cr), 0.05 to 1.15% of nickel (Ni), 0.18 to 0.3% of nitrogen (N), 0.4 to 2.8% of copper (Cu), and the remainder of iron (Fe) and inevitable impurities; and
hot rolling, hot annealing, coiling, cooling, cold rolling, and cold annealing the slab,
wherein a predicted pitting potential of the stainless steel obtained by Equation (1) below is from 360 to 440 mV:

$$\text{Pitting potential} = -623.2 + 47.4Creq \text{ ...... Equation (1)}$$

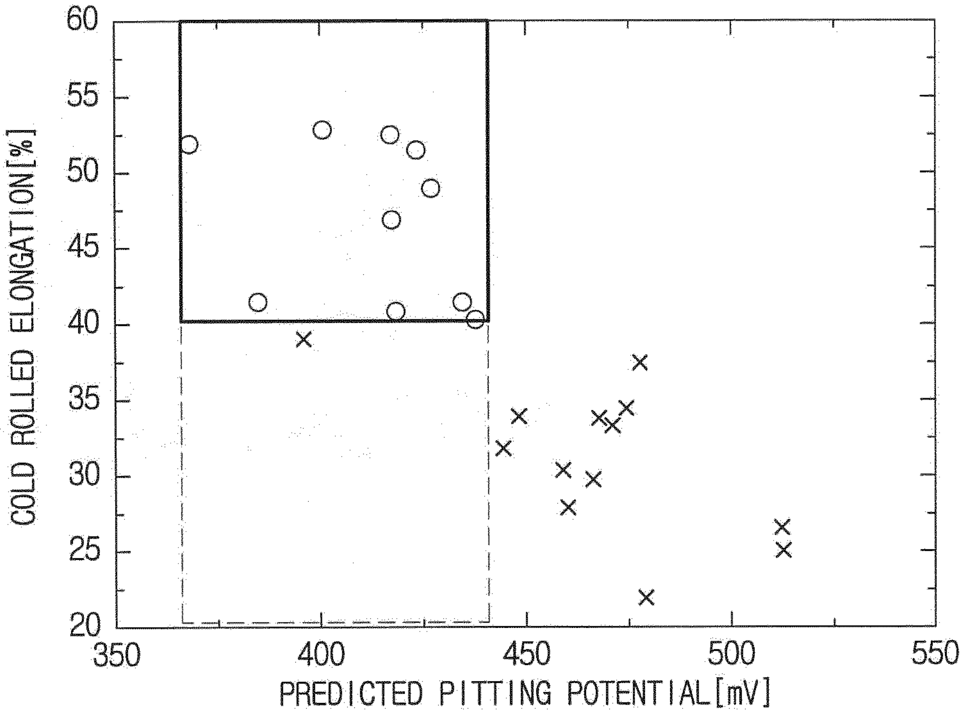
$$(Creq = Cr + 1.37Mo + 0.75W + 1.5Si + 2Nb + 3Ti + 5V + 5.5Al).$$

11. The method of claim 10, wherein a coiling temperature and a cooling speed after coiling of a hot annealed steel satisfy Equation (3) below:

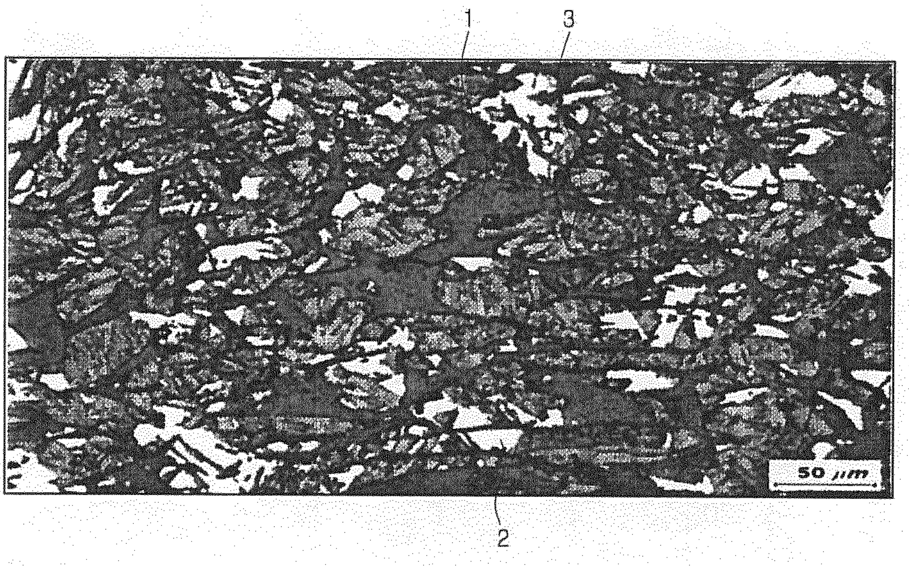
$$A \leq 690 + 25*\log B \text{ ...... Equation (3)}$$

wherein A is coiling temperature (°C) B is cooling speed after coiling (°C/sec).

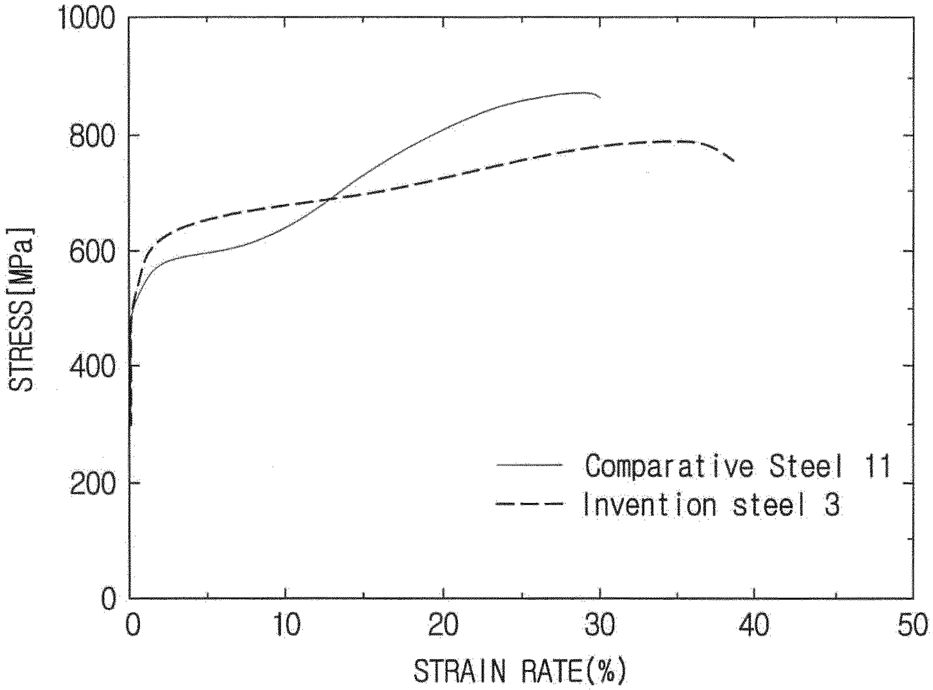
【FIG. 1】


60
55
50
45
40
35
30
25
20
COLD ROLLED ELONGATION[%]
350
400
450
500
550
PREDICTED PITTING POTENTIAL[mV]

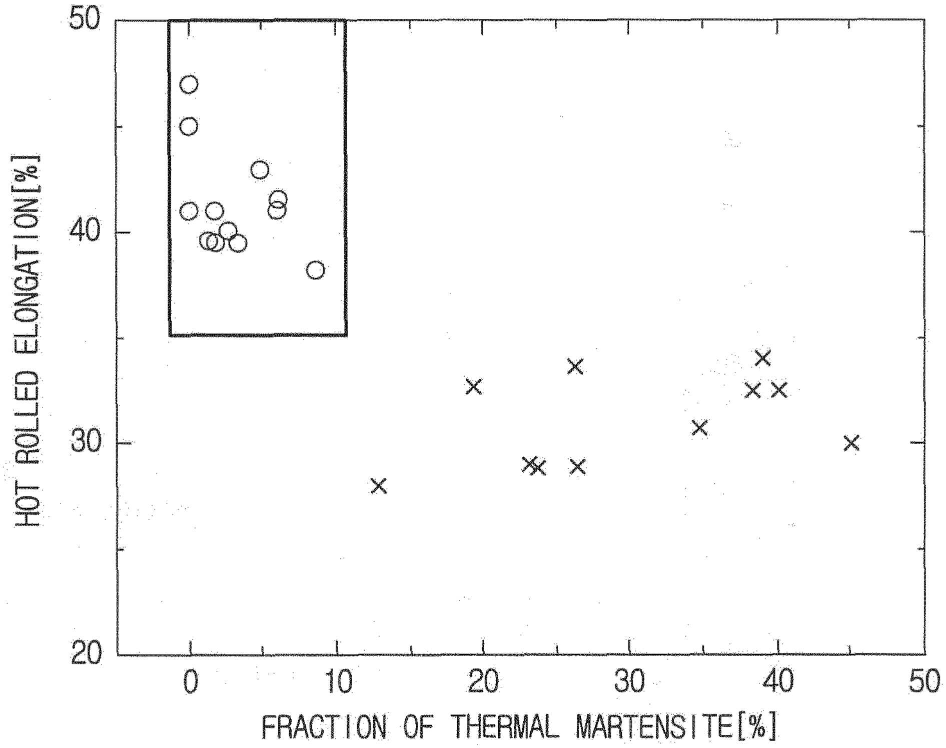
【FIG. 2】



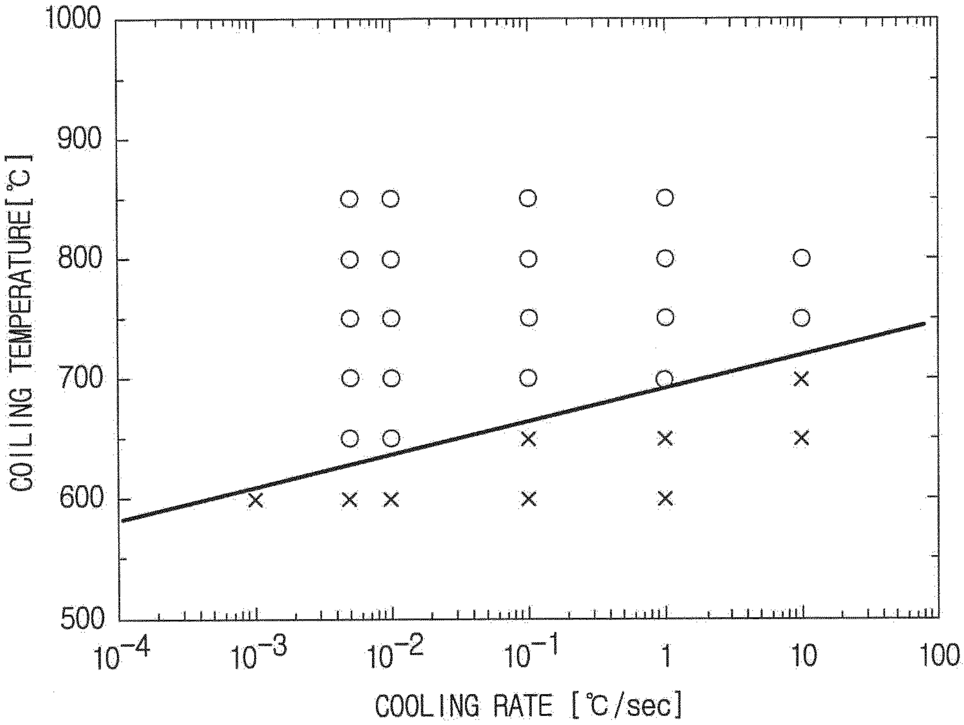
【FIG. 3】


1000
800
600
400
200
0
STRESS[MPa]
0
10
20
30
40
50
STRAIN RATE(%)
Comparative Steel 11
Invention steel 3

【FIG. 4】


50
40
30
20
HOT ROLLED ELONGATION[%]
0
10
20
30
40
50
FRACTION OF THERMAL MARTENSITE[%]

【FIG. 5】


1000
900
800
700
600
500
COILING TEMPERATURE[℃]
10^-4
10^-3
10^-2
10^-1
1
10
100
COOLING RATE [℃/sec]

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2016/008881

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/58(2006.01)i, C22C 38/42(2006.01)i, C22C 38/04(2006.01)i, C22C 38/02(2006.01)i, C22C 38/00(2006.01)i, C22C 38/44(2006.01)i, C22C 38/50(2006.01)i, C22C 38/48(2006.01)i, C22C 38/46(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; C21D 6/00; C22C 38/00; C22C 38/44; C21D 7/02; B22D 11/06; C22C 38/52; C22C 38/42; C22C 38/04; C22C 38/02; C22C 38/50; C22C 38/48; C22C 38/46; C21D 8/02

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: lean duplex, corrosion-resistive, workability, Cr, Ni, Mn, Si, stainless, pitting potential

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 10-2015-0073381 A (POSCO) 01 July 2015 See abstract, paragraphs [0037]-[0040] and claims 1-7.	1-2,5-9
Y		3-4,10-11
Y	WO 2015-086903 A1 (OUTOKUMPU OYJ.) 18 June 2015 See claim 12.	3
Y	EP 2410068 A1 (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORPORATION) 25 January 2012 See claim 2.	4
Y	KR 10-2014-0069945 A (POSCO) 10 June 2014 See abstract and claims 3-4.	10-11
A	US 2011-0097234 A1 (OIKAWA, Yuusuke et al.) 28 April 2011 See abstract and claim 1.	1-11

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

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

Date of the actual completion of the international search	Date of mailing of the international search report
17 NOVEMBER 2016 (17.11.2016)	**17 NOVEMBER 2016 (17.11.2016)**

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Facsimile No. 82-42-472-7140	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
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