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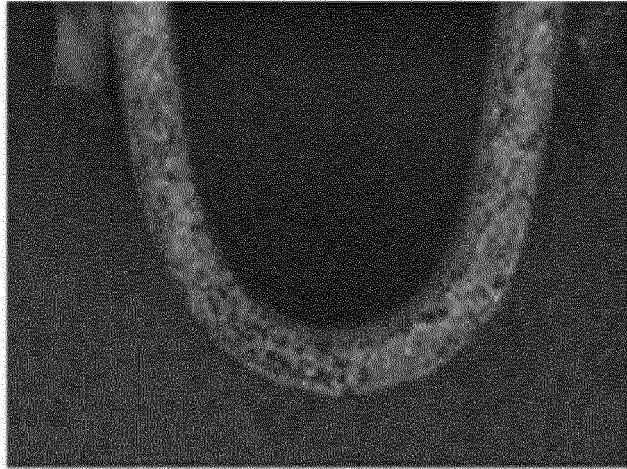
(54) **AUSTENITIC HIGH MANGANESE STEEL FOR CRYOGENIC APPLICATIONS HAVING
EXCELLENT SURFACE QUALITY AND RESISTANCE TO STRESS CORROSION CRACKING,
AND MANUFACTURING METHOD FOR SAME**

(57) An aspect of the present invention can provide an austenitic high manganese steel for cryogenic applications and a manufacturing method for same, wherein the austenitic high manganese steel for cryogenic applications effectively ensures resistance to stress corrosion cracking by inducing the formation of twin crystals in cor-

rosion and transformation composite environments, and effectively ensures surface quality by suppressing the formation of cracks in the surface of the steel.

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【Fig.2】



Description

[Technical Field]

[0001] The present disclosure relates to an austenitic high manganese steel for cryogenic applications appropriate for a fuel tank, a storage tank, a ship membrane, a transport pipe, and the like, for storage and transport of liquefied petroleum gas, liquefied natural gas and the like, and a manufacturing method for the same, and more particularly, to an austenitic high manganese steel for cryogenic applications in which a surface quality is effectively secured by suppressing formation of grooves in a surface and resistance to stress corrosion cracking is effectively secured, and a manufacturing method for the same.

[Background Art]

[0002] In accordance with tightening of regulations on environmental pollution and petroleum energy expected to be depleted, demand for eco-friendly energy such as liquefied natural gas (LNG), liquefied petroleum gas (LPG) and the like as alternative energy has increased, and interest in development of use technology has increased. In accordance with an increase in a demand for low-polluting fuels such as LNG and LPG transported in a low-temperature liquid state, development of materials for low-temperature structures for storage and transportation of the non-polluting fuels has increased. The materials for low-temperature structures require mechanical properties such as low-temperature strength and toughness, and an aluminum alloy, an austenitic stainless steel, a 35% Invar steel, and a 9% Ni steel have been used as such materials. Among these materials, the 9% Ni steel exhibits excellent mechanical properties in terms of weldability and economical efficiency, and has thus been currently the most widely used as the material for low-temperature structures.

[0003] However, since the 9% Ni steel has ferrite as a matrix structure, a diffusion speed of hydrogen is high, such that brittleness due to hydrogen, that is, resistance to stress corrosion cracking, is inferior, and application of the 9% Ni steel to an environment involving deformation and corrosion is not preferable. In addition, a 304 stainless steel, which is a typical austenitic steel, has a problem that when deformation is applied to the 304 stainless steel, a slip band is formed on a surface layer and a dense oxide layer is broken, such that local corrosion occurs, and resistance to stress corrosion cracking is thus low. Therefore, development of a material having excellent low-temperature toughness and excellent resistance to stress corrosion cracking has been urgently demanded.

[0004] An austenitic high manganese (Mn) steel has high toughness because austenite is stable even at room temperature or cryogenic temperature by adjusting contents of manganese (Mn) and carbon (C), which are elements that increase stability of the austenite. Therefore, the austenitic high manganese (Mn) steel may be used as a material of a fuel tank, a storage tank, a ship membrane, a transport pipe, and the like, for storage and transport of liquefied petroleum gas, liquefied natural gas and the like requiring cryogenic properties.

[0005] However, since the high manganese (Mn) steel contains a large amount of manganese (Mn), which has a strong oxidation tendency, some of grain boundary oxidations formed at the time of reheating a slab are removed as scale, but some of the grain boundary oxidations grow into cracks at the time of hot rolling and may remain as surface flaws on a surface of a product. Therefore, at the time of manufacturing the high manganese (Mn) steel, a grinding process of the surface of the product may follow, which is not preferable in terms of economical efficiency and productivity.

(Related Art Document)

[0006] (Patent Document 1) Korea Patent Laid-Open Publication No. 10-2015-0075275 (published on July 3, 2015)

[Disclosure]

[Technical Problem]

[0007] An aspect of the present disclosure is to provide an austenitic high manganese steel for cryogenic applications in which resistance to stress corrosion cracking is effectively secured by inducing formation of twin crystals in a composite environment of corrosion and deformation and a surface quality is effectively secured by suppressing formation of surface flaws on a surface of the austenitic high manganese steel, and a manufacturing method for the same.

[0008] An object of the present disclosure is not limited to the abovementioned contents. Those skilled in the art will have no difficulty in understanding an additional object of the present disclosure from the general contents of the present specification.

[Technical Solution]

[0009] According to an aspect of the present disclosure, an austenitic high manganese steel for cryogenic applications having excellent surface quality and resistance to stress corrosion cracking contains: by wt%, 0.4 to 0.5% of C, 23 to 26% of Mn, 0.05 to 0.5% of Si, 3 to 5% of Cr, 0.3 to 0.7% of Cu, 0.05% or less of S, 0.5% or less of P, 0.001 to 0.05% of Al, 0.005% or less of B, the balance Fe, and inevitable impurities; and 95 area% or more of austenite as a fine structure, wherein stacking fault energy (SFE) represented by the following Relational Equation 1 is 150 mJ/m² or more, and at the time of observing a cross section using an optical microscope, the number of surface flaws formed at a depth of 10 μm or more from a surface is 0.0001 or less per unit area (mm²) with respect to a cross-sectional area from the surface to a point of t/8 (here, t refers to a product thickness),

[Relational Equation 1]

$$\text{Stacking Fault Energy (SFE)} = 25.7 + 2 \cdot \text{Ni} - 0.9 \cdot \text{Cr} + 410 \cdot \text{C} - 13 \cdot \text{Si} - 1.2 \cdot \text{Mn}$$

[0010] (In Relational Equation 1, Ni, Cr, C, Si, and Mn refer wt% of each component, and when a corresponding component is not contained, its value is 0).

[0011] When the austenitic high manganese steel is applied with stress of a yield strength level and then immersed in a 25% NaCl solution at 100°C, a stress corrosion cracking generation time may be 900 hours or more.

[0012] The austenitic high manganese steel may have yield strength of 400 MPa or more and Charpy impact toughness of 41 J or more at -196°C.

[0013] According to another aspect of the present disclosure, a manufacturing method for an austenitic high manganese steel for cryogenic applications having excellent surface quality and resistance to stress corrosion cracking includes: reheating a slab in a temperature range of 1000 to 1150°C, the slab containing, by wt%, 0.4 to 0.5% of C, 23 to 26% of Mn, 0.05 to 0.5% of Si, 3 to 5% of Cr, 0.3 to 0.7% of Cu, 0.05% or less of S, 0.5% or less of P, 0.001 to 0.05% of Al, 0.005% or less of B, the balance Fe, and inevitable impurities; rough-rolling the reheated slab to provide a rough rolled bar; finish-rolling the rough rolled bar in a temperature range of 750 to 1000°C to provide a hot rolled material; and controlling a reheating temperature (T_{SR}) of the slab and a rolling reduction (R_{PM}) of the rough rolling so as to satisfy the following Relational Equation 2, wherein stacking fault energy (SFE) of the slab represented by the following Relational Equation 1 is 150 mJ/m² or more,

[Relational Equation 1]

$$\text{Stacking Fault Energy (SFE)} = 25.7 + 2 \cdot \text{Ni} - 0.9 \cdot \text{Cr} + 410 \cdot \text{C} - 13 \cdot \text{Si} - 1.2 \cdot \text{Mn}$$

[0014] (In Relational Equation 1, Ni, Cr, C, Si, and Mn refer wt% of each component, and when a corresponding component is not contained, its value is 0),

[Relational Equation 2]

$$R_{PM}/T_{SR} > 0.15$$

[0015] (In Relational Equation 2, R_{PM} and T_{SR} refer to a rolling reduction (mm) of rough rolling and a reheating temperature (°C) of the slab, respectively).

[0016] The finish-rolled hot rolled material may be acceleration-cooled to 600°C or less at a cooling rate of 10°C/s or more.

[0017] The technical solution does not enumerate all of the features of the present description, and various features of the present disclosure and advantages and effects according to the various features will be understood in more detail with reference to the following specific exemplary embodiments.

[Advantageous Effects]

[0018] As set forth above, according to an exemplary embodiment in the present disclosure, an austenitic high manganese steel for cryogenic applications in which resistance to stress corrosion cracking is effectively secured by inducing formation of twin crystals in a composite environment of corrosion and deformation, and a manufacturing method for the same may be provided.

[0019] In addition, according to an exemplary embodiment in the present disclosure, an austenitic high manganese steel for cryogenic applications in which a surface quality is effectively secured by suppressing formation of surface flaws on a surface of the austenitic high manganese steel, and a manufacturing method for the same may be provided.

[Description of Drawings]

[0020] FIGS. 1 and 2 are captured photographs of stress corrosion cracking test results of Specimen 1 and Specimen 4.

[Best Mode for Invention]

[0021] The present disclosure relates to an austenitic high manganese steel for cryogenic applications having excellent surface quality and resistance to stress corrosion cracking, and a manufacturing method for the same, and exemplary embodiments in the present disclosure will hereinafter be described. Exemplary embodiments in the present disclosure may be modified to have several forms, and it is not to be interpreted that the scope of the present disclosure is limited to exemplary embodiments described below. Exemplary embodiments in the present disclosure are provided in order to further describe the present disclosure in detail to those skilled in the art to which the present disclosure pertains.

[0022] Hereinafter, compositions of a steel according to the present disclosure will be described in more detail. Hereinafter, unless otherwise indicated, % indicating a content of each element is based on weight.

[0023] An austenitic high manganese steel for cryogenic applications having excellent surface quality and resistance to stress corrosion cracking according to an exemplary embodiment in the present disclosure may contain, by wt%, 0.4 to 0.5% of C, 23 to 26% of Mn, 0.05 to 0.5% of Si, 3 to 5% of Cr, 0.3 to 0.7% of Cu, 0.05% or less of S, 0.5% or less of P, 0.001 to 0.05% of Al, 0.005% or less of B, the balance Fe, and inevitable impurities.

Carbon (C) : 0.4 to 0.5%

[0024] Carbon (C) is an element that is effective in stabilizing austenite in a steel and securing strength by solid solution strengthening. Therefore, in the present disclosure, a lower limit of a content of carbon (C) may be limited to 0.4% in order to secure low-temperature toughness and strength. The reason is that when the content of carbon (C) is less than 0.4%, yield strength may be decreased, austenite stability may be decreased, such that ferrite or martensite may be formed, and low-temperature toughness may be decreased. On the other hand, when the content of carbon (C) exceeds a predetermined range, excessive carbide may be formed at the time of cooling after rolling. Thus, in the present disclosure, an upper limit of the content of carbon (C) may be limited to 0.5%. Therefore, the content of carbon (C) of the present disclosure may be 0.4 to 0.5%.

Manganese (Mn): 23 to 26%

[0025] Manganese (Mn) is an important element that serves to stabilize austenite. Therefore, in the present disclosure, a lower limit of a content of manganese (Mn) may be limited to 23% in order to achieve such an effect. That is, the austenitic high manganese steel for cryogenic applications having excellent surface quality and resistance to stress corrosion cracking according to an exemplary embodiment in the present disclosure contains 23% or more of manganese (Mn), and austenite stability may thus be effectively increased. Therefore, formation of ferrite, ϵ -martensite, and α' -martensite may be suppressed to effectively secure low-temperature toughness. On the other hand, when the content of manganese (Mn) is a predetermined level or more, an austenite stability increase effect is saturated, while manufacturing costs are significantly increased, and internal oxidation is excessively generated during hot rolling, such that a surface quality may become inferior. Thus, in the present disclosure, an upper limit of the content of manganese (Mn) may be limited to 26%. Therefore, the content of manganese (Mn) of the present disclosure may be 23 to 26%.

Silicon (Si) : 0.05 to 0.5%

[0026] Silicon (Si) is a deoxidizing agent like aluminum (Al), and is an element that is indispensably added in a trace amount. However, when silicon (Si) is excessively added, oxide may be formed at a grain boundary to reduce high-temperature ductility and cause a crack or the like, thereby deteriorating a surface quality. Therefore, in the present

disclosure, an upper limit of a content of silicon (Si) may be limited to 0.50%. On the other hand, an excessive cost is required in order to reduce the content of silicon (Si) in the steel. Thus, in the present disclosure, a lower limit of the content of silicon (Si) may be limited to 0.05%. Therefore, the content of silicon (Si) of the present disclosure may be 0.05 to 0.50%.

Chromium (Cr) : 3 to 5%

[0027] Chromium (Cr) is an element that contributes to an increase in strength through solid solution strengthening in austenite. In addition, chromium (Cr) is an element that has excellent corrosion resistance and thus effectively contributes to prevention of deterioration of a surface quality due to high-temperature oxidation. Therefore, in the present disclosure, a lower limit of a content of chromium (Cr) may be limited to 3% in order to achieve such an effect. On the other hand, when the content of chromium (Cr) is a predetermined level or more, a cryogenic toughness decreases due to generation of carbide is problematic. Thus, in the present disclosure, an upper limit of the content of chromium (Cr) may be limited to 5%. Therefore, the content of chromium (Cr) of the present disclosure may be 3 to 5%.

Copper (Cu) : 0.3 to 0.7%

[0028] Copper (Cu) is an austenite stabilizing element, is an element that stabilizes austenite along with manganese (Mn) and carbon (C), and is an element that contributes to improvement of low-temperature toughness. In addition, since copper (Cu) is an element of which a solid solubility in carbide is very low and diffusion in austenite is slow, copper (Cu) is an element that is concentrated on an interface between austenite and carbide and surrounds a nucleus of fine carbide to effectively suppress generation and growth of carbide due to additional diffusion of carbon (C). Therefore, in the present disclosure, a lower limit of a content of copper (Cu) may be limited to 0.3% in order to achieve such an effect. However, when the content of copper (Cu) is a predetermined level or more, deterioration of a surface quality due to hot shortness may be problematic. Thus, in the present disclosure, an upper limit of the content of copper (Cu) may be limited to 0.7%. Therefore, the content of copper (Cu) of the present disclosure may be 0.3 to 0.7%.

Sulfur (S) : 0.05% or less

[0029] In order to suppress hot shortness due to formation of inclusions, in the present disclosure, an upper limit of a content of sulfur (S) may be actively suppressed, and a preferable upper limit of the content of sulfur (S) may be 0.05%.

Phosphorus (P): 0.5% or less

[0030] Phosphorus (P) is an element that is easily segregated and is an element that causes cracking at the time of casting or deteriorates weldability. Therefore, in the present disclosure, an upper limit of a content of phosphorus (P) may be actively suppressed, and a preferable upper limit of the content of phosphorus (P) may be 0.5%.

Aluminum (Al) : 0.001 to 0.05%

[0031] Aluminum (Al) is a representative element that is added as a deoxidizing agent. Therefore, in the present disclosure, a lower limit of a content of aluminum (Al) may be limited to 0.001%, and more preferably 0.005%, in order to achieve such an effect. However, aluminum (Al) may react with carbon (C) and nitrogen (N) to form precipitates, and hot workability may be deteriorated due to these precipitates. Thus, in the present disclosure, an upper limit of the content of aluminum (Al) may be limited to 0.05%. A more preferable upper limit of the content of aluminum (Al) may be 0.045%.

Boron (B) : 0.005% or less

[0032] Boron (B) is an element that contributes to improvement of a surface quality by suppressing an intergranular fracture through strengthening of a grain boundary. Therefore, in the present disclosure, boron (B) may be added in order to achieve such an effect, and a more preferable lower limit of a content of boron (B) may be 0.0001%. However, when boron (B) is excessively added, toughness and weldability may be deteriorated due to formation of coarse precipitates, or the like. Thus, in the present disclosure, an upper limit of the content of boron (B) may be limited to 0.005%.

[0033] The austenitic high manganese steel for cryogenic applications having excellent surface quality and resistance to stress corrosion cracking according to an exemplary embodiment in the present disclosure may contain the balance Fe and other inevitable impurities in addition to the components described above. However, in a general manufacturing process, unintended impurities may inevitably be mixed from a raw material or the surrounding environment, and thus, these impurities may not be excluded. Since these impurities are known to those skilled in the art, all the contents are

not specifically mentioned in the present specification. In addition, addition of effective components other than the compositions described above is not excluded.

[0034] In the austenitic high manganese steel for cryogenic applications having excellent surface quality and resistance to stress corrosion cracking according to an exemplary embodiment in the present disclosure, contents of alloy components may be controlled so that stacking fault energy (SFE) represented by the following Relational Equation 1 is 150 mJ/m² or more.

[Relational Equation 1]

$$\text{Stacking Fault Energy (SFE)} = 25.7 + 2 \cdot \text{Ni} - 0.9 \cdot \text{Cr} + 410 \cdot \text{C} - 13 \cdot \text{Si} - 1.2 \cdot \text{Mn}$$

[0035] (In Relational Equation 1, Ni, Cr, C, Si, and Mn refer wt% of each component, and when a corresponding component is not contained, its value is 0)

[0036] The inventors of the present disclosure have found that resistance to stress corrosion cracking may be effectively improved by inducing formation of twin crystals in stress and corrosion environments, when the stacking fault energy (SFE) defined by the above Relational Equation 1 is controlled to be a predetermined level or more, as a result of performing an in-depth study on a generation mechanism of stress corrosion cracking. It can be seen that in a case of a 304 stainless steel, deformation occurs due to an action of dislocation, such that a slip band or a slip step is formed on a surface of the 304 stainless steel, and local corrosion is accelerated, resulting in stress corrosion cracking that develops into a crack, while in the high manganese steel according to the present disclosure, the stacking fault energy (SFE) represented by Relational Equation 1 is controlled to be 150 mJ/m² or more, such that twin crystals are formed in stressful and corrosive environments, and excellent resistance to stress corrosion cracking is thus secured. That is, when the austenitic high manganese steel for cryogenic applications having excellent surface quality and resistance to stress corrosion cracking according to an exemplary embodiment in the present disclosure is applied with stress of a yield strength level and then immersed in a 25% NaCl solution at 100°C, a stress corrosion cracking generation time is 900 hours or more, and excellent resistance to stress corrosion cracking may thus be secured.

[0037] In addition, the austenitic high manganese steel for cryogenic applications having excellent surface quality and resistance to stress corrosion cracking according to an exemplary embodiment in the present disclosure contains 95 area% or more of austenite as a fine structure, and at the time of observing a cross section using an optical microscope, the number of surface flaws formed at a depth of 10 μm or more from a surface may be 0.0001 or less per unit area (mm²) with respect to a cross-sectional area from the surface to a point of t/8 (here, t refers to a product thickness).

[0038] That is, in the austenitic high manganese steel for cryogenic applications having excellent surface quality and resistance to stress corrosion cracking according to an exemplary embodiment in the present disclosure, formation of surface flaws on a product surface is actively suppressed through strict process condition control as described below. Therefore, a surface quality is effectively secured, such that a subsequent process such as a grinding process or the like may be omitted, and economical efficiency and productivity may thus be effectively secured.

[0039] In addition, since the austenitic high manganese steel for cryogenic applications having excellent surface quality and resistance to stress corrosion cracking according to an exemplary embodiment in the present disclosure has yield strength of 400 MPa or more and Charpy impact toughness of 41 J or more at -196°C, an austenitic high manganese steel particularly appropriate as a material of a fuel tank, a storage tank, a ship membrane, a transport pipe, and the like, for storage and transport of liquefied petroleum gas, liquefied natural gas and the like requiring cryogenic properties may be provided.

[0040] A manufacturing method according to the present disclosure will hereinafter be described in more detail.

[0041] The manufacturing method for an austenitic high manganese steel for cryogenic applications having excellent surface quality and resistance to stress corrosion cracking according to an exemplary embodiment in the present disclosure may include: reheating a slab in a temperature range of 1000 to 1150°C, the slab containing, by wt%, 0.4 to 0.5% of C, 23 to 26% of Mn, 0.05 to 0.5% of Si, 3 to 5% of Cr, 0.3 to 0.7% of Cu, 0.05% or less of S, 0.5% or less of P, 0.001 to 0.05% of Al, 0.005% or less of B, the balance Fe, and inevitable impurities; rough-rolling the reheated slab to provide a rough rolled bar; finish-rolling the rough rolled bar in a temperature range of 750 to 1000°C to provide a hot rolled material; and controlling a reheating temperature (T_{SR}) of the slab and a rolling reduction (R_{PM}) of the rough rolling so as to satisfy the following Relational Equation 2, wherein stacking fault energy (SFE) of the slab represented by the following Relational Equation 1 is 150 mJ/m² or more.

[Relational Equation 1]

$$\text{Stacking Fault Energy (SFE)} = 25.7 + 2 \cdot \text{Ni} - 0.9 \cdot \text{Cr} +$$

$$410 \cdot \text{C} - 13 \cdot \text{Si} - 1.2 \cdot \text{Mn}$$

[0042] (In Relational Equation 1, Ni, Cr, C, Si, and Mn refer wt% of each component, and when a corresponding component is not contained, its value is 0)

[Relational Equation 2]

$$R_{RM}/T_{SR} > 0.15$$

[0043] (In Relational Equation 2, R_{RM} and T_{SR} refer to a rolling reduction (mm) of rough rolling and a reheating temperature (°C) of the slab, respectively)

[0044] In addition, the finish-rolled hot rolled material may be acceleration-cooled to 600°C or less at a cooling rate of 10°C/s or more.

Reheating Slab

[0045] A steel composition of the slab corresponds to the steel composition of the austenitic high manganese steel described above, and a description for the steel composition of the slab is thus replaced by the description for the steel composition of the austenitic high manganese steel described above. In addition, a description for stacking fault energy (SFE) of the slab is also replaced by the description for the stacking fault energy (SFE) of the austenitic high manganese steel described above.

[0046] The slab having the steel composition described above may be uniformly heated in a temperature range of 1000 to 1150°C. A thickness of the slab provided in the reheating of the slab may be about 250 mm, but the scope of the present disclosure is not necessarily limited thereto.

[0047] In order to prevent a rolling load from being excessively applied in subsequent hot rolling, a lower limit of a slab reheating temperature may be limited to 1000°C. In addition, as a heating temperature becomes higher, the ease of hot rolling is secured, but when a steel in which a content of manganese (Mn) is high is heated at a high temperature, grain boundary oxidations may be severely generated in the steel. Thus, in the present disclosure, an upper limit of the slab reheating temperature may be limited to 1150°C.

Hot Rolling

[0048] After a slab reheating process, a hot rolling process of rough-rolling the reheated slab to be a rough rolled bar and finish-rolling the rough rolled bar in a temperature range of 750 to 1000°C to provide a hot rolled material may be involved. As a finish rolling temperature of hot rolling becomes higher, a deformation resistance decreases, such that the ease of rolling is secured, but as the finish rolling temperature becomes higher, deterioration of a surface quality due to grain boundary oxidations is caused. Thus, the finish rolling temperature of the present disclosure may be limited to 750 to 1000°C.

[0049] Since the austenitic high manganese steel according to the present disclosure contains a large amount of manganese (Mn) having strong oxidizing properties, grain boundary oxidations are inevitably generated even when a temperature of a heating furnace is limited. Even though some of the formed grain boundary oxidations are removed as scales during the reheating of the slab, the remaining grain boundary oxidations grow into cracks during hot rolling to form surface flaws on a surface of a product, such that a surface quality of the product is deteriorated.

[0050] The inventors of the present disclosure came to the conclusion that it is effective to make a structure fine by allowing recrystallization to occur as quickly as possible after heating the slab in order to minimize growth of grain boundary oxidations remaining on a surface of the slab into cracks during hot rolling, through an in-depth study. However, an increase in a deformation speed is the most effective in order to promote the recrystallization, and the increase in the deformation speed is a factor that may be achieved through an increase in a rolling reduction of rough rolling, but when the rolling reduction excessively increases, separately from minimizing the growth of grain boundary oxidations into cracks, damage to a facility due to an excessive rolling load, or the like, may be problematic.

[0051] Therefore, the inventors of the present disclosure have derived the following Relational Equation 2 for controlling a rolling load of hot rolling to be a threshold value or less while actively suppressing the formation of the surface flaws

of the product through repeated experiments.

[Relational Equation 2]

5

$$R_{RM}/T_{SR} > 0.15$$

[0052] (In Relational Equation 2, R_{RM} and T_{SR} refer to a rolling reduction (mm) of rough rolling and a reheating temperature (°C) of the slab, respectively)

10 **[0053]** That is, in the present disclosure, a rolling reduction of rough rolling with respect to a temperature of a heating furnace is controlled to be in a predetermined range as in the above Relational Equation 2, such that when the temperature of the heating furnace is high, the rolling reduction of the rough rolling may be relatively increased to suppress growth of grain boundary oxidations into surface flaws during hot rolling, and when the temperature of the heating furnace is low, the rolling reduction of the rough rolling may be relatively decreased to decrease a rolling load applied to a rolling mill during hot rolling. Thus, an optimal slab heating condition and hot rolling condition may be provided.

Acceleration Cooling

20 **[0054]** After the hot rolling process, the finish-rolled hot rolled material may be acceleration-cooled to 600°C or less at a cooling rate of 10°C/s or more. Since the austenitic high manganese steel according to the present disclosure contains 3 to 5% of chromium (Cr) and C, a cooling rate of the hot rolled material is controlled to be 10°C/s or more to effectively prevent a decrease in low-temperature toughness due to carbide precipitation. In addition, in general acceleration-cooling, it is difficult to implement a cooling rate exceeding 100°C/s due to characteristics of a facility. Thus, in the present disclosure, an upper limit of the cooling rate may be limited to 100°C/s.

25 **[0055]** In addition, even though the hot rolled material is cooled at the cooling rate of 10°C/s or more, when the cooling is stopped at a high temperature, it is highly likely that carbides will be generated and grown. Thus, in the present disclosure, a cooling stop temperature may be limited to 600°C.

30 **[0056]** The austenitic high manganese steel manufactured as described above contains 95 area% or more of austenite as a fine structure, and at the time of observing a cross section using an optical microscope, the number of surface flaws formed at a depth of 10 μm or more from a surface may be 0.0001 or less per unit area (mm²) with respect to a cross-sectional area from the surface to a point of t/8 (here, t refers to a product thickness), and the austenitic high manganese steel may have yield strength of 400 MPa or more and Charpy impact toughness of 41 J or more at -196°C.

35 **[0057]** In addition, when the austenitic high manganese steel manufactured as described above is applied with stress of a yield strength level and then immersed in a 25% NaCl solution at 100°C, a stress corrosion cracking generation time is 900 hours or more, and excellent resistance to stress corrosion cracking may thus be secured.

[Mode for Invention]

40 **[0058]** Hereinafter, the present disclosure will be described in more detail through Inventive Example. However, it is to be noted that Inventive Example to be described later is for illustrating and embodying the present disclosure and is not intended to limit the scope of the present disclosure.

(Inventive Example)

45 **[0059]** A slab having a composition of Table 1 was manufactured to have a thickness of 250 mm, and specimens were manufactured and prepared under process conditions of Table 2. Each specimen was prepared by performing finish-rolling in a temperature range of 750 to 1000°C, and performing acceleration-cooling to 600°C or less at a cooling rate of 10°C/s or more. For each specimen, impact absorption energy, yield strength, whether or not surface flaws have been formed, and stress corrosion cracking characteristics were evaluated, and evaluation results were shown together in Table 2. The impact absorption energy was evaluated at -196°C using a plate-shaped specimen having a notch of 2 mm in accordance with ASTM E23, which is a standard test method. A tensile test was evaluated with a one-way tensile tester by processing a plate-shaped specimen conforming to ASTM E8/E8M, which is a standard test method. A depth and the number of surface flaws was evaluated by cutting a specimen in a thickness direction to prepare the specimen according to ASTM E112, and then measuring a depth of the largest surface flaw in an observation region and the number of surface flaws having a depth of 10 μm or more per unit area in the observation region using an optical microscope. The stress corrosion cracking characteristics were evaluated by an ASTM G123 standard method as illustrated in FIG. 2, and were evaluated by applying stress of a yield strength level to the specimen for a test, immersing the specimen in a 25% NaCl solution at 100°C, and measuring a time when a fracture occurs.

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[Table 1]

Division	Composition (wt%)									SFE (mJ/m ²)
	Mn	Ni	Cr	C	Cu	B	Si	P	S.Al	
Steel Type 1	2.0	10	18	0.08	-	-	1.0	0.045	0.03	46.9
Steel Type 2	23. 2	-	3.5	0.44	0.50	0.0012	0.041	0.027	0.036	174.6
Steel Type 3	24. 6	-	3.4	0.46	0.52	0.0028	0.311	0.014	0.039	177.7

[Table 2]

Specimen No.	Division	Reheating Temperature (°C)	Rolling Reduction (mm) of Rough Rolling	Relational Equation 2	Maximum Surface Flaw Depth (μm)	Number of Surface Flaws (Number/m m ²)	Impact Absorption Energy (J. @-196°C)	Yield Strength (MPa)	Stress Corrosion Cracking Generation Time (hr)	Remark
1	Steel Type 1	1130	170	0.155	-	-	-	322	120	Comparative Example
2	Steel Type 2	1145	180	0.157	0	0	92	322	900	Comparative Example
3	Steel Type 2	1130	150	0.133	30	0.03	97	402	950	Inventive Example
4	Steel Type 3	1115	168	0.151	0	0	105	458	1000	Comparative Example
5	Steel Type 3	1147	160	0.139	25	0.02	99	464	1000	Inventive Example

[0060] It can be seen that in Specimen 1, which is a 304 stainless steel specimen, a slip band is formed under stress and corrosive environments, such that resistance to stress corrosion cracking is remarkably inferior. Since surface quality and low-temperature property measurements were not performed on Specimen 1, measurement result values were not described. It can be seen that in a case of Specimens 2 to 5, a range of stacking fault energy (SFE) limited by the present disclosure is satisfied, and twin crystals are thus formed under stress and corrosion environments, such that excellent resistance to stress corrosion cracking is secured. FIGS. 1 and 2 are captured photographs of stress corrosion cracking test results of Specimen 1 and Specimen 4, and it can be clearly confirmed with the naked eye that a crack occurred in a case of Specimen 1, whereas a crack did not occur in a case of Specimen 4.

[0061] In addition, it can be seen that Specimens 2 to 4 that satisfy a manufacturing condition of the present disclosure have excellent surface quality because occurrence of surface flaws is suppressed, whereas Specimens 3 and 5 that do not satisfy the manufacturing condition of the present disclosure have a poor surface quality because surface flaws occur.

[0062] While the present disclosure has been described in detail through exemplary embodiment, other types of exemplary embodiments are also possible. Therefore, the technical spirit and scope of the claims set forth below are not limited to exemplary embodiments.

Claims

1. An austenitic high manganese steel for cryogenic applications having excellent surface quality and resistance to stress corrosion cracking, comprising:

by wt%, 0.4 to 0.5% of C, 23 to 26% of Mn, 0.05 to 0.5% of Si, 3 to 5% of Cr, 0.3 to 0.7% of Cu, 0.05% or less of S, 0.5% or less of P, 0.001 to 0.05% of Al, 0.005% or less of B, the balance Fe, and inevitable impurities; and 95 area% or more of austenite as a fine structure,

wherein stacking fault energy (SFE) represented by the following Relational Equation 1 is 150 mJ/m² or more, and at the time of observing a cross section using an optical microscope, the number of surface flaws formed at a depth of 10 μm or more from a surface is 0.0001 or less per unit area (mm²) with respect to a cross-sectional area from the surface to a point of t/8 (here, t refers to a product thickness),

[Relational Equation 1]

$$\text{Stacking Fault Energy (SFE)} = 25.7 + 2 \cdot \text{Ni} - 0.9 \cdot \text{Cr} + 410 \cdot \text{C} \\ - 13 \cdot \text{Si} - 1.2 \cdot \text{Mn}$$

(in Relational Equation 1, Ni, Cr, C, Si, and Mn refer wt% of each component, and when a corresponding component is not contained, its value is 0).

2. The austenitic high manganese steel of claim 1, wherein when the austenitic high manganese steel is applied with stress of a yield strength level and then immersed in a 25% NaCl solution at 100°C, a stress corrosion cracking generation time is 900 hours or more.
3. The austenitic high manganese steel of claim 1, wherein the austenitic high manganese steel has yield strength of 400 MPa or more and Charpy impact toughness of 41 J or more at -196°C.
4. A manufacturing method for an austenitic high manganese steel for cryogenic applications having excellent surface quality and resistance to stress corrosion cracking, comprising:

reheating a slab in a temperature range of 1000 to 1150°C, the slab comprising, by wt%, 0.4 to 0.5% of C, 23 to 26% of Mn, 0.05 to 0.5% of Si, 3 to 5% of Cr, 0.3 to 0.7% of Cu, 0.05% or less of S, 0.5% or less of P, 0.001 to 0.05% of Al, 0.005% or less of B, the balance Fe, and inevitable impurities;

rough-rolling the reheated slab to provide a rough rolled bar;

finish-rolling the rough rolled bar in a temperature range of 750 to 1000°C to provide a hot rolled material; and controlling a reheating temperature (T_{SR}) of the slab and a rolling reduction (R_{PM}) of the rough rolling so as to satisfy the following Relational Equation 2,

wherein stacking fault energy (SFE) of the slab represented by the following Relational Equation 1 is 150 mJ/m² or more,

[Relational Equation 1]

$$\text{Stacking Fault Energy (SFE)} = 25.7 + 2 \cdot \text{Ni} - 0.9 \cdot \text{Cr} + 410 \cdot \text{C} \\ - 13 \cdot \text{Si} - 1.2 \cdot \text{Mn}$$

(In Relational Equation 1, Ni, Cr, C, Si, and Mn refer wt% of each component, and when a corresponding component is not contained, its value is 0), and

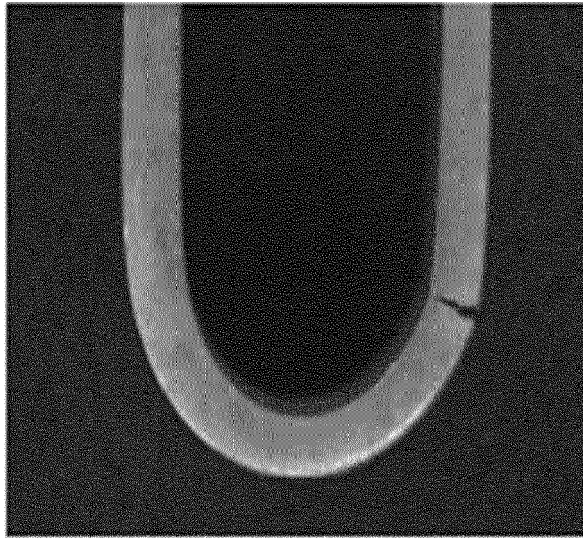
[Relational Equation 2]

$$R_{\text{RM}}/T_{\text{SR}} > 0.15$$

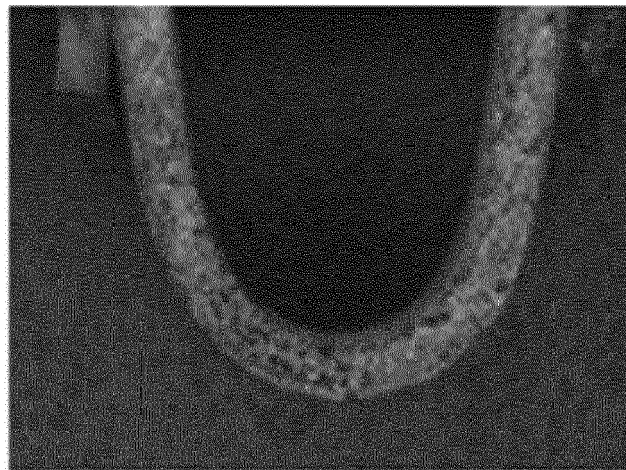
(In Relational Equation 2, R_{RM} and T_{SR} refer to a rolling reduction (mm) of rough rolling and a reheating temperature (°C) of the slab, respectively).

5. The manufacturing method of claim 4, wherein the finish-rolled hot rolled material is acceleration-cooled to 600°C or less at a cooling rate of 10°C/s or more.

【Fig.1】



【Fig.2】



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2019/014156

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/38(2006.01)i, C22C 38/20(2006.01)i, C22C 38/32(2006.01)i, B21B 3/00(2006.01)i, B21B 37/16(2006.01)i, B21B 37/74(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 38/38; B21B 1/22; B21B 3/00; C21D 8/02; C21D 9/46; C22C 38/00; C22C 38/04; C22C 38/58; C22C 38/20; C22C 38/32; B21B 37/16; B21B 37/74

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) & Key words: high manganese, austenite, roughing mill, reheating, reduction

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KR 10-2000-0041265 A (POHANG IRON & STEEL CO., LTD.) 15 July 2000 See claims 1-2.	1-5
A	KR 10-2017-0075657 A (POSCO) 03 July 2017 See paragraphs [0093]-[0099] and claims 1-4.	1-5
A	JP 2009-542920 A (ARCELORMITTAL FRANCE et al.) 03 December 2009 See claims 1, 21.	1-5
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A	US 2016-0186285 A1 (POSCO) 30 June 2016 See claims 1, 3-4.	1-5

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

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

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International application No.

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