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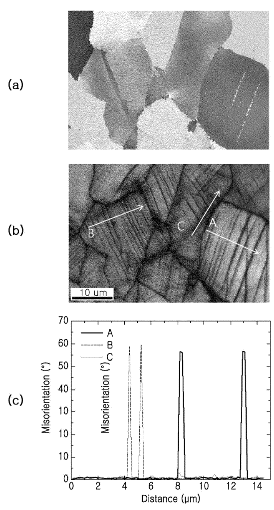
(54) **HIGH MANGANESE AUSTENITIC STEEL HAVING HIGH YIELD STRENGTH AND MANUFACTURING METHOD FOR SAME**

(57) A high manganese austenitic steel having high yield strength according to one aspect of the present invention, comprises: by wt%, 0.2% to 0.5% of C, 20% to 28% of Mn, 0.05% to 0.5% of Si, 0.03% or less of P, 0.005% or less of S, 0.005% to 0.05% of Al, and the remainder being Fe and other unavoidable impurities; and 95 area% or more of austenite as a microstructure, wherein the grain boundary fraction in crystal grains of the microstructure may be 7 area% or more.

【Fig. 2】



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Description

[Technical Field]

[0001] The present disclosure relates to an austenitic high manganese steel and a manufacturing method for the same, and more particularly, to an austenitic high manganese steel having excellent ductility and excellent yield strength, and a manufacturing method for the same.

[Background Art]

[0002] An austenitic high manganese steel has high toughness because austenite is stable even in an environment at room temperature or a cryogenic temperature by adjusting contents of manganese (Mn) and carbon (C), which are elements increasing stability of austenite.

[0003] However, a high manganese steel having austenite as a main structure has an advantage that low-temperature toughness is excellent due to characteristics of a ductile fracture even at a low temperature, but has a technical limitation in decreasing costs by decreasing a design thickness of a material at the time of designing a structure because strength, particularly, yield strength, is low due to a face centered cubic structure, which is a unique crystal structure.

[0004] Therefore, in order to increase the strength of the austenitic high manganese steel, technologies such as solid solution strengthening through addition of an alloying element, precipitation hardening through addition of a precipitate-forming element, and pancaking rolling through control of finish rolling temperature have been proposed. However, there are problems such as an increase in an economic cost due to the addition of the alloying element, a limitation in generation of precipitates due to a high solubility limit of precipitates in austenite, and a decrease in impact toughness due to an increase in strength at the time of pancaking rolling through control of a finish rolling temperature, and the increase in the strength of the high manganese steel is thus accompanied by significant technical disadvantages. Accordingly, development of an austenitic high manganese steel having high strength while maintaining a predetermined level or more of elongation through an economical and effective method has been demanded.

(Related Art Document)

[0005] (Patent Document 1) Korean Patent Laid-Open Publication No. 10-2015-0075324 (published on July 3, 2015)

[Disclosure]

[Technical Problem]

[0006] An aspect of the present disclosure is to provide an austenitic high manganese steel having excellent yield strength, and a manufacturing method for the same.

[0007] 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]

[0008] According to an aspect of the present disclosure, an austenitic high manganese steel having excellent yield strength contains: by wt%, 0.2 to 0.5% of C, 20 to 28% of Mn, 0.05 to 0.5% of Si, 0.03% or less of P, 0.005% or less of S, 0.005 to 0.05% of Al, a balance of Fe, and other inevitable impurities; and 95 area% or more of austenite as a microstructure, wherein a grain boundary fraction in a crystal grain of the microstructure is 7 area% or more.

[0009] The austenitic high manganese steel may further contain, by wt%, 0.0005 to 0.01% of B.

[0010] The austenitic high manganese steel may further contain, by wt%, one or more selected from 1.0% or less of Cu and 5.0% or less of Cr.

[0011] Stacking fault energy (SFE) of the austenitic high manganese steel represented by the following Relational Equation 1 may be in the range of 10 to 19 mJ/m^2,

[Relational Equation 1]

$$\text{Stacking Fault Energy (SFE)} = -24.9 + 0.814*Mn + 44.3*C - 0.62*Si + 1.06*Cu + 7.9*Al - 0.555*Cr$$

[0012] (In Relational Equation 1, Mn, C, Si, Cu, Al, and Cr refer wt% of each alloy composition).

[0013] An average grain size of the austenite may be 5 to 150 μm.

[0014] The grain boundary fraction in the crystal grain in the microstructure may be 80 area% or less.

[0015] The austenitic high manganese steel may have a yield strength of 400 MPa or more, a tensile strength of 800 MPa or more, an elongation of 30% or more, and a Charpy impact toughness of 30 J or more (based on a thickness of 5 mm) based on -196°C.

[0016] According to another aspect of the present disclosure, a manufacturing method for an austenitic high manganese steel having excellent yield strength includes: a reheating step of reheating a slab in a temperature range of 1050 to 1300°C, the slab comprising, by wt%, 0.2 to 0.5% of C, 20 to 28% of Mn, 0.05 to 0.5% of Si, 0.03% or less of P, 0.005% or less of S, 0.005 to 0.05% of Al, a balance of Fe, and other inevitable impurities; a hot rolling step of hot rolling the reheated slab at a finish rolling temperature of 800 to 1050°C to provide a hot rolled material; a cooling step of accelerated-cooling the hot rolled material to a temperature range of 600°C or less at a cooling rate of 10 to 100°C; and a weak reducing step of weakly reducing the accelerated-cooled hot rolled material at a reduction ratio of 0.1 to 10% in a temperature range of 25 to 400°C.

[0017] The slab may further contain, by wt%, 0.0005 to 0.01% of B.

[0018] The slab may further contain, by wt%, one or more selected from 1.0% or less of Cu and 5.0% or less of Cr.

[0019] Stacking fault energy (SFE) of the slab represented by the following Relational Equation 1 may be in the range of 10 to 19 mJ/m^2,

[Relational Equation 1]

$$\text{Stacking Fault Energy (SFE)} = -24.9 + 0.814*Mn + 44.3*C - 0.62*Si + 1.06*Cu + 7.9*Al - 0.555*Cr$$

[0020] (In Relational Equation 1, Mn, C, Si, Cu, Al, and Cr refer to wt% of contents of each component).

[0021] A reduction ratio of the weak reducing step may be 1 to 5%.

[0022] 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]

[0023] As set forth above, according to an exemplary embodiment in the present disclosure, an austenitic high manganese steel having excellent ductility and excellent yield strength, and a manufacturing method for the same may be provided.

[Description of Drawings]

[0024]

FIG. 1 is a view illustrating a result obtained by observing a microstructure of Specimen 1.

FIG. 2 is a view illustrating a result obtained by observing a microstructure of Specimen 10.

[Best Mode for Invention]

[0025] The present disclosure relates to an austenitic high manganese steel having excellent yield strength 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 into several forms, and it is not to be interpreted that the scope of the present disclosure is limited to exemplary embodiments described below. The present exemplary embodiments are provided in order to further describe the present disclosure in detail to those skilled in the art to which the present disclosure pertains.

[0026] 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.

[0027] An austenitic high manganese steel having excellent yield strength according to an exemplary embodiment in the present disclosure may contain, by wt%, 0.2 to 0.5% of C, 20 to 28% of Mn, 0.05 to 0.5% of Si, 0.03% or less of P, 0.005% or less of S, 0.005 to 0.05% of Al, a balance of Fe, and other inevitable impurities.

Carbon (C) : 0.2 to 0.5%

[0028] Carbon (C) is an element that is effective in stabilizing austenite of 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 0.2% in order to secure low-temperature toughness and strength. The reason is that when the content of carbon (C) is less than 0.2%, stability of austenite is insufficient, such that stable austenite may not be obtained at a cryogenic temperature, and stain induced transformation into ε-martensite and α'-martensite is easily caused by external stress, such that toughness and strength of the steel may be decreased. A more preferable lower limit of the content of carbon (C) may be 0.3%. On the other hand, when the content of carbon (C) exceeds a predetermined range, toughness of the steel may be rapidly deteriorated due to precipitation of carbide, and strength of the steel may become excessively high, such that workability of the steel may be significantly decreased. Thus, in the present disclosure, an upper limit of the content of carbon (C) may be limited to 0.5%. A more preferable upper limit of the content of carbon (C) may be 0.45%.

Manganese (Mn): 20 to 28%

[0029] Manganese (Mn) is an important element that serves to stabilize austenite. Thus, in the present disclosure, a lower limit of a content of manganese (Mn) may be limited to 20% in order to achieve such an effect. That is, the austenitic high manganese steel having excellent yield strength according to an exemplary embodiment in the present disclosure contains 20% or more of manganese (Mn), and stability of austenite may thus be effectively increased. Therefore, formation of ferrite, ε-martensite, and α'-martensite may be suppressed to effectively secure low-temperature toughness of the steel. A preferable lower limit of the content of manganese (Mn) may be 22%, and a more preferable lower limit of the content of manganese (Mn) may be 23%. On the other hand, when the content of manganese (Mn) exceeds a predetermined level of range, an austenite stability increase effect is saturated, while manufacturing costs may be significantly increased, and internal oxidation is excessively generated during hot rolling, such that a surface quality may be inferior. Thus, in the present disclosure, an upper limit of the content of manganese (Mn) may be limited to 28%. A preferable upper limit of the content of manganese (Mn) may be 26%, and a more preferable upper limit of the content of manganese (Mn) may be 25%.

Silicon (Si): 0.05 to 0.50%

[0030] 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, excessive costs may be 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%.

Phosphorus (P): 0.03% or less

[0031] 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 limited to 0.03% in order to prevent castability deterioration and weldability deterioration. In addition, in the present disclosure, a lower limit of the content of phosphorus (P) is not particularly limited, but may be limited to 0.001% in consideration of a steelmaking burden.

Sulfur (S): 0.005% or less

[0032] Sulfur (S) is an element that causes a hot shortness defect due to formation of inclusions. Therefore, in the present disclosure, an upper limit of a content of sulfur (S) may be limited to 0.005% in order to suppress occurrence of hot shortness. In addition, in the present disclosure, a lower limit of the content of sulfur (S) is not particularly limited, but may be limited to 0.0005% in consideration of a steelmaking burden.

Aluminum (Al): 0.05% or less

[0033] 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%.

[0034] The austenitic high manganese steel having excellent yield strength according to an exemplary embodiment in the present disclosure may further contain, by wt%, 0.0005 to 0.01% of B, and may further contain, by wt%, one or more selected from 1.0% or less of Cu and 5.0% or less of Cr.

Copper (Cu): 1% or less

[0035] Copper (Cu) 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 of the steel. 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, copper (Cu) may be added in order to secure low-temperature toughness, and copper (Cr) may be added in excess of 0%. A preferable lower limit of a content of copper (Cu) may be 0.3%, and a more preferable lower limit of the content of copper (Cu) may be 0.4%. On the other hand, when the content of copper (Cu) exceeds 1%, hot workability of the steel may be deteriorated. Thus, in the present disclosure, an upper limit of the content of copper (Cu) may be limited to 1%. A preferable upper limit of the content of copper (Cu) may be 0.9%, and a more preferable upper limit of the content of copper (Cu) may be 0.7%.

Chromium (Cr): 5.0% or less

[0036] Chromium (Cr) is an element that contributes to improvement of impact toughness at a low temperature by stabilizing austenite to a range of an appropriate addition amount, and is solid-dissolved in austenite to increase strength of the steel. In addition, chromium is also an element that improves corrosion resistance of the steel. Therefore, chromium (Cr) may be added in order to achieve such an effect, and chromium (Cr) may be added in excess of 0%. A preferable lower limit of a content of chromium (Cr) may be 1.2%, and a more preferable lower limit of the content of chromium (Cr) may be 2.5%. However, chromium (Cr) is a carbide-forming element and is an element that decreases low-temperature impact by forming carbide at the austenite grain boundary, and thus, in the present disclosure, an upper limit of the content of chromium (Cr) may be limited to 5.0% in consideration of a content relationship between carbon (C) and other elements added together. A preferable upper limit of the content of chromium (Cr) may be 4.5%, and a more preferable upper limit of the content of chromium (Cr) may be 4.0%.

Boron (B) : 0.0005 to 0.01%

[0037] Boron (B) is a grain boundary strengthening element that strengthens an austenite grain boundary, and is an element that may effectively lower high-temperature cracking sensitivity of the steel by strengthening the austenite grain boundary even when it is added in a small amount. Therefore, in order to achieve such an effect, in the present disclosure, 0.0005% or more of boron (B) may be added. A preferable lower limit of a content of boron (B) may be 0.001%, and a more preferable lower limit of the content of boron (B) may be 0.002%. On the other hand, when the content of boron (B) exceeds a predetermined range, segregation is caused at the austenite grain boundary to increase high-temperature cracking sensitivity of the steel, and a surface quality of the steel may thus be deteriorated. Thus, in the present disclosure, an upper limit of the content of boron (B) may be limited to 0.01%. A preferable upper limit of the content of boron (B) may be 0.008%, and a more preferable upper limit of the content of boron (B) may be 0.006%.

[0038] The austenitic high manganese steel having excellent yield strength according to an exemplary embodiment in the present disclosure may contain a balance of 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 completely 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.

[0039] The austenitic high manganese steel having excellent yield strength according to an exemplary embodiment in the present disclosure contains 95 area% or more of austenite as a microstructure, and cryogenic toughness of the austenitic high manganese steel may thus be effectively secured. An average grain size of austenite may be 5 to 150 μm. The average grain size of austenite that may be implemented in a manufacturing process is 5 μm or more, and when the average grain size of austenite significantly increases, strength of the steel may be decreased. Thus, a grain size of austenite may be limited to 150 μm or less.

[0040] A grain boundary fraction in a crystal grain of the austenitic high manganese steel having excellent yield strength according to an exemplary embodiment in the present disclosure may be 7 area% or more, and a preferable grain boundary fraction in the crystal grain may be 10% or more. A grain boundary in the crystal grain of the present disclosure may be interpreted as the meaning including a grain boundary newly formed in a weak reduction process to be described later. That is, a microstructure having a certain crystal grain may be formed in the steel by a series of processes such as slab heating, hot rolling, and cooling, and in some cases, a very small amount of deformed structure may be formed in one crystal grain. In a case of the present disclosure, weak reduction is performed after cooling, and a large amount of a new deformed structure may thus be formed in the crystal grain, and the grain boundary in the crystal grain of the present disclosure can be interpreted as a concept including a grain boundary newly introduced into the crystal grain through the weak reduction process as described above. In addition, the grain boundary in the crystal grain of the present disclosure may be interpreted as a concept including both of a high angle grain boundary and a low angle grain boundary. Since the austenitic high manganese steel of the present disclosure is manufactured by introducing the weak reduction process, a grain boundary in the crystal grain of 7 area% or more, and a grain boundary in the crystal grain of preferably 10% or more are formed, and yield strength of the steel may accordingly be effectively secured.

[0041] On the other hand, when the grain boundary in the grain is excessively formed, yield strength of the steel may increase, while elongation of the steel may become rapidly inferior. Therefore, in the present disclosure, an upper limit of the grain boundary fraction in the crystal grain may be limited to 80 area% for both yield strength and elongation of the steel. A more preferable upper limit of the grain boundary fraction in the crystal grain may be 60 area%.

[0042] The austenitic high manganese steel having excellent yield strength according to an exemplary embodiment in the present disclosure may contain carbide and/or ε-martensite as a structure that may exist, other than austenite. When a fraction of carbide and/or ε-martensite exceeds a predetermined level, toughness and ductility of the steel may be rapidly deteriorated. Thus, in the present disclosure, the fraction of carbide and/or ε-martensite may be limited to 5 area% or less.

[0043] In the austenitic high manganese steel having excellent yield strength according to an exemplary embodiment in the present disclosure, a content range of an alloy component may be limited so that stacking fault energy (SFE) represented by the following Relational Equation 1 is in the range of 10 to 19 mJ/m^2.

[Relational Equation 1]

$$\text{Stacking Fault Energy (SFE)} = -24.9 + 0.814*Mn + 44.3*C - 0.62*Si + 1.06*Cu + 7.9*Al - 0.555*Cr$$

[0044] (In Relational Equation 1, Mn, C, Si, Cu, Al, and Cr refer wt% of contents of each component)

[0045] When the stacking fault energy (SFE) represented by Relational equation 1 is less than 10 mJ/m^2, ε-martensite and α'-martensite may be formed, and particularly when α'-martensite is generated, low-temperature toughness may be rapidly deteriorated. A more preferable stacking fault energy (SFE) may be 11 mJ/m^2 or more. In addition, as the stacking fault energy (SFE) represented by Relational Equation 1 increases, stability of austenite increases, but when a value of stacking fault energy (SFE) exceeds 19 mJ/m^2, it is not preferable in view of efficiency of addition of an alloying element. A more preferable upper limit of the stacking fault energy (SFE) may be 16 mJ/m^2.

[0046] The austenitic high manganese steel having excellent yield strength according to an exemplary embodiment in the present disclosure has a yield strength of 400 MPa or more, a tensile strength of 800 MPa or more, an elongation of 30% or more, and a Charpy impact toughness of 30 J or more (based on a thickness of 5 mm) based on -196°C, and a structural steel particularly appropriate for a cryogenic environment may thus be provided.

[0047] A manufacturing method according to the present disclosure will hereinafter be described in more detail.

[0048] The manufacturing method for an austenitic high manganese steel having excellent yield strength according to an exemplary embodiment in the present disclosure may include: a reheating step of reheating a slab in a temperature range of 1050 to 1300°C; a hot rolling step of hot rolling the reheated slab at a finish rolling temperature of 800 to 1050°C to provide a hot rolled material; a cooling step of cooling the hot rolled material to a temperature range of 600°C or less at a cooling rate of 1 to 100°C; and a weak reducing step of weakly reducing the cooled hot rolled material at a reduction ratio of 0.1 to 10% in a temperature range of 25 to 400°C.

Slab Reheating

[0049] The slab provided in the manufacturing method according to the present disclosure has a steel composition corresponding to a steel composition of the austenitic high manganese steel described above, and a description for a steel composition and stacking fault energy (SFE) of the slab is thus replaced by the description for the steel composition and the stacking fault energy (SFE) of the austenitic high manganese steel described above.

[0050] The slab having the steel composition described above may be reheated in a temperature range of 1050 to 1300°C. When a reheating temperature is less than a predetermined range, an excessive rolling load may occur during hot rolling or an alloy component may not be sufficiently solid-dissolved. Thus, in the present disclosure, a lower limit of a reheating temperature range of the slab may be limited to 1050°C. On the other hand, when the reheating temperature exceeds a predetermined range, strength of the steel may be decreased due to excessive growth of a crystal grain or the slab may be reheated beyond a solidus line temperature of the steel, such that a hot rolling property of the steel may become inferior. Thus, in the present disclosure, an upper limit of the reheating temperature range of the slab may be limited to 1300°C.

Hot Rolling

[0051] A hot rolling process includes a rough rolling process and a finish rolling process, and the reheated slab may be hot-rolled and provided as a hot rolled material. In this case, hot finish rolling is preferably performed in a temperature range of 800 to 1050°C. The reason is that when a hot finish rolling temperature is less than a predetermined range, excessive rolling load due to an increase in a rolling load may be problematic, and when the hot finish rolling temperature exceeds a predetermined range, crystal grains grow coarsely, such that target strength may not be obtained. At the time of hot rolling, a reduction ratio may be adjusted to be in a predetermined range depending on a desired thickness of the steel.

Accelerated Cooling

[0052] The hot rolled material may be cooled to a cooling stop temperature of 600°C or less at a cooling rate of 1 to 100°C/s. When the cooling rate is less than a predetermined range, a decrease in ductility of the steel by carbide deposited at a grain boundary during cooling and deterioration of wear resistance due to the decrease in the ductility of the steel may be problematic. Thus, in the present disclosure, the cooling rate of the hot rolled material may be limited to 1°C/s or more. A preferable lower limit of the cooling rate may be 10°C/s, and a cooling manner may be accelerated-cooling. The faster the cooling rate, the more advantageous the carbide precipitation suppressing effect, but in general accelerated-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.

[0053] 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.

Weak Reduction

[0054] A process of weakly rolling the hot rolled material during being cooled or the hot rolled material for which the cooling has been completed at a reduction ratio of 0.1 to 10% in a temperature range of 25 to 400°C may be involved. When a weak reduction temperature is excessively low, there is a possibility of phase transformation to ε-martensite or α'-martensite during the weak reduction. Thus, in the present disclosure, a lower limit of a temperature range of the weak reduction process may be limited to 25°C, and a more preferable lower limit of the temperature range of the weak reduction process in terms of a decrease in a rolling load may be 100°C. When the weak reduction temperature is excessively high, a desired strength improving effect may not be achieved. Thus, in the present disclosure, an upper limit of the temperature range of the weak reduction process may be limited to 400°C.

[0055] In the present disclosure, a reduction ratio of the weak reduction may be limited to 0.1% or more in order to achieve the desired strength improving effect. A preferable lower limit of the reduction ratio of the weak reduction may be 0.5%, and a more preferable lower limit of the reduction ratio of the weak reduction may be 1.0%. In addition, in the present disclosure, the reduction ratio of the weak reduction may be limited to 10% or less in order to prevent a decrease in elongation of the steel. A preferable upper limit of the reduction ratio of the weak reduction may be 8%, and a more preferable upper limit of the reduction ratio of the weak reduction may be 5%.

[0056] The austenitic high manganese steel manufactured as described above contains 95 area% or more of austenite as a microstructure, and may have a grain boundary fraction in a crystal grain of 7 area% or more, a yield strength of 400 MPa or more, a tensile strength of 800 MPa or more, an elongation of 30% or more, and a Charpy impact toughness of 30 J or more (based on a thickness of 5 mm) based on -196°C.

[Mode for Invention]

[0057] 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)

[0058] A slab having an alloy composition of Table 1 was prepared, and each specimen was manufactured by applying a manufacturing process of Table 2. SFE in Table 1 refers stacking fault energy (mJ/m^2) calculated through Relational Equation 1, and Specimens 1, 6, and 11 in Table 2 are specimens in a case in which weak reduction is not applied.

[Table 1]

Divisi on	Alloy Composition (wt%)								SFE (mJ/m^2)
	Mn	C	Si	Cu	Al	Cr	P	S	
Steel Type 1	23.57	0.41	0.300	0.418	0.0184	3.08	0.012	0.0015	11.1
Steel Type 2	24.36	0.44	0.265	0.505	0.0315	3.39	0.011	0.0016	13.16
Steel Type 3	22.1	0.385	0.22	0.2	0.026	1.95	0.012	0.0015	9.34

[Table 2]

Division		Slab Heating		Hot Rolling		Cooling		Weak Reduction	
Speci men No.	Steel Type	Heating Furnace Temperature (°C)	Extracti on temper at ure (°C)	Finish Rolling Temperatu re (°C)	Final Thicknes s (mm)	Cooling rate (°C/s)	Cooling stop temper at ure (°C)	Plate Temperat ure (°C)	Reduction Ratio (%)
1	Steel Type 1	1186	1178	902	6	10	300		
2	Steel Type 1	1186	1178	902	6	10	300	25	1
3	Steel Type 1	1186	1178	902	6	10	300	25	3
4	Steel Type 1	1186	1178	902	6	10	300	25	5
5	Steel Type 1	1186	1178	902	6	10	300	25	10
6	Steel Type 2	1190	1182	895	8	12	310	-	-
7	Steel Type 2	1190	1182	895	8	12	310	400	1
8	Steel Type 2	1190	1182	895	8	12	310	400	3
9	Steel Type 2	1190	1182	895	8	12	310	400	5
10	Steel Type 2	1190	1182	895	8	12	310	400	10
11	Steel Type 3	1216	1191	929	9	15	290	-	-

[0059] Microstructures, tensile properties, and impact toughness of each specimen were evaluated, and evaluation results were shown in Table 3. The microstructures of each specimen were observed using a scanning electron microscope (SEM) and an electron backscatter diffraction (EBSD), and grain size fractions in a crystal grain were measured using Image Quality Map of the EBSD. The tensile properties were tested at room temperature according to American Society for Testing Materials (ASTM) A370, and the impact toughness was also measured at -196°C by processing into impact specimens having a thickness of 5 mm, processed according to a condition of the same standard.

[Table 3]

Division		Microstructure	Tensile Property			C-direction Impact Toughness (J, @-196°C)
Specimen No.	Steel Type	Grain Size Fraction in Crystal Grain (Area %)	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	
1	Steel Type 1	6.6	529	877	54	44
2	Steel Type 1	30.8	572	922	54	40
3	Steel Type 1	54.0	623	952	48	35
4	Steel Type 1	59.1	686	988	43	32
5	Steel Type 1	68.3	757	1063	34	25
6	Steel Type 2	3.5	468	871	61	46
7	Steel Type 2	15.9	503	891	60	45
8	Steel Type 2	39.2	550	901	58	43
9	Steel Type 2	50.5	612	913	54	40
10	Steel Type 2	56.7	722	981	48	33
11	Steel Type 3	3.1	417	917	53	18

[0060] As shown in Tables 1 to 3, it may be confirmed that yield strength was increased to a level of about 10% or more in Specimens 2 to 5 and Specimens 7 to 10 that satisfy an alloy composition and a processing condition of the present disclosure as compared with Specimens 1 and 6 on which weak reduction was not performed.

[0061] FIG. 1 is a view illustrating a result obtained by observing a microstructure of Specimen 1 using an EBSD. FIG. 1(a) is an IPF map, showing the same brightness (or saturation) within a boundary means one grain, and showing different brightness (or saturation) means different crystal orientations, that is, different grains. FIG. 1(b) is an IQ map for the same structure as that of FIG. 1(a), and it may be confirmed that there are almost no other deformed structures in crystal grains.

[0062] FIG. 2 is a view illustrating a result obtained by observing a microstructure of Specimen 10 using an EBSD. FIG. 2(a) is also an IPF map, showing the same brightness (or saturation) within a boundary means one grain, and showing different brightness (or saturation) means different crystal orientations, that is, different grains. FIG. 2(b) is also an IQ map for the same structure as that of FIG. 2(a), and it may be confirmed that deformed structures were generated in crystal grains. FIG. 2(c) illustrates grain boundary angles according to arrow lengths in FIG. 2(b), and it may be confirmed that new grain boundaries having low angle and high angle characteristics were generated in crystal grains from lines A, B, and C. That is, it may be confirmed from FIGS. 2 (a) to 2 (c) that a large amount of new grain boundaries were formed at grain boundaries through a weak reduction process in Specimen 10 unlike Specimen 1.

[0063] 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 having excellent yield strength, comprising:

by wt%, 0.2 to 0.5% of C, 20 to 28% of Mn, 0.05 to 0.5% of Si, 0.03% or less of P, 0.005% or less of S, 0.005 to 0.05% of Al, a balance of Fe, and other inevitable impurities; and 95 area% or more of austenite as a microstructure,
wherein a grain boundary fraction in a crystal grain of the microstructure is 7 area% or more.

2. The austenitic high manganese steel of claim 1, further comprising, by wt%, 0.0005 to 0.01% of B.

3. The austenitic high manganese steel of claim 1, further comprising, by wt%, one or more selected from 1.0% or less of Cu and 5.0% or less of Cr.

4. The austenitic high manganese steel of claim 3, wherein stacking fault energy (SFE) of the austenitic high manganese steel represented by the following Relational Equation 1 is in the range of 10 to 19 mJ/m^2,

[Relational Equation 1]

$$\text{Stacking Fault Energy (SFE)} = -24.9 + 0.814*Mn + 44.3*C - 0.62*Si + 1.06*Cu + 7.9*Al - 0.555*Cr,$$

in Relational Equation 1, Mn, C, Si, Cu, Al, and Cr refer wt% of each alloy composition.

5. The austenitic high manganese steel of claim 1, wherein an average grain size of the austenite is 5 to 150 μm.

6. The austenitic high manganese steel of claim 1, wherein the grain boundary fraction in the crystal grain in the microstructure is 80 area% or less.

7. The austenitic high manganese steel of claim 1, wherein the austenitic high manganese steel has a yield strength of 400 MPa or more, a tensile strength of 800 MPa or more, an elongation of 30% or more, and a Charpy impact toughness of 30 J or more (based on a thickness of 5 mm) based on -196°C.

8. A manufacturing method for an austenitic high manganese steel having excellent yield strength, comprising:

a reheating step of reheating a slab in a temperature range of 1050 to 1300°C, the slab comprising, by wt%, 0.2 to 0.5% of C, 20 to 28% of Mn, 0.05 to 0.5% of Si, 0.03% or less of P, 0.005% or less of S, 0.005 to 0.05% of Al, a balance of Fe, and other inevitable impurities;
a hot rolling step of hot rolling the reheated slab at a finish rolling temperature of 800 to 1050°C to provide a hot rolled material;

a cooling step of accelerated-cooling the hot rolled material to a temperature range of 600°C or less at a cooling rate of 10 to 100°C; and
a weak reducing step of weakly reducing the accelerated-cooled hot rolled material at a reduction ratio of 0.1 to 10% in a temperature range of 25 to 400°C.

9. The manufacturing method of claim 8, wherein the slab comprises, by wt%, 0.0005 to 0.01% of B.

10. The manufacturing method of claim 8, wherein the slab comprises, by wt%, one or more selected from 1.0% or less of Cu and 5.0% or less of Cr.

11. The manufacturing method of claim 10, wherein stacking fault energy (SFE) of the slab represented by the following Relational Equation 1 is in the range of 10 to 19 mJ/m^2,

[Relational Equation 1]

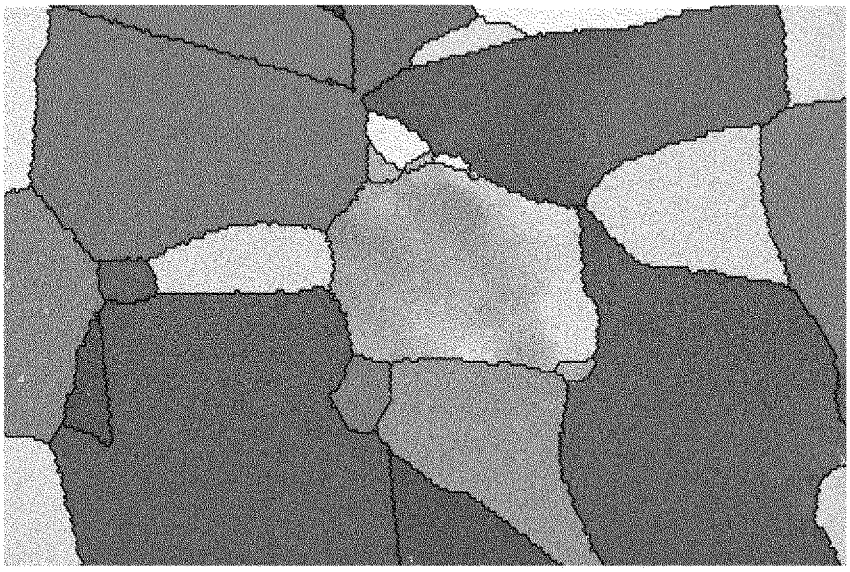
$$\text{Stacking Fault Energy (SFE)} = -24.9 + 0.814*Mn + 44.3*C - 0.62*Si + 1.06*Cu + 7.9*Al - 0.555*Cr,$$

in Relational Equation 1, Mn, C, Si, Cu, Al, and Cr refer wt% of contents of each component.

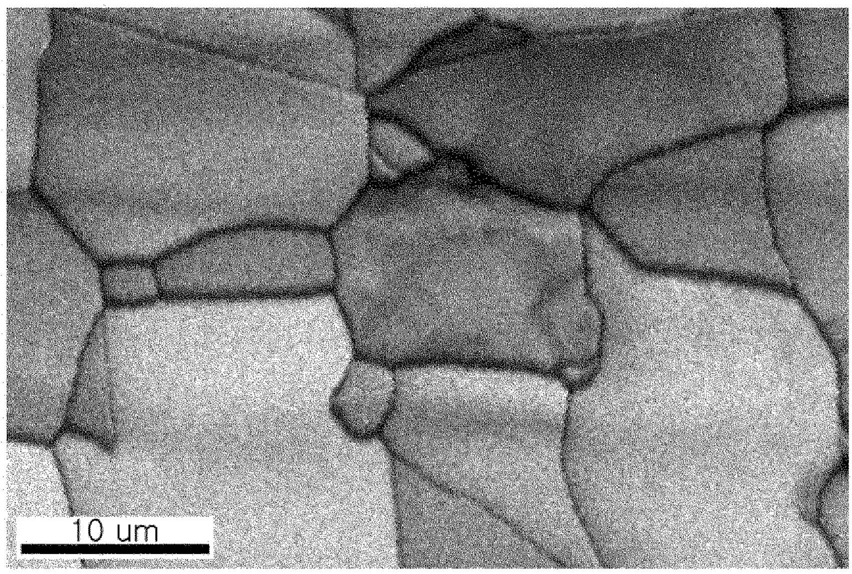
12. The manufacturing method of claim 8, wherein a reduction ratio of the weak reducing step is 1 to 5%.

【Fig. 1】

(a)

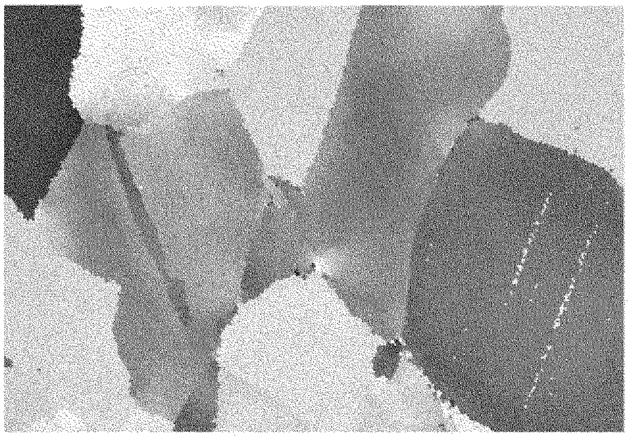


(b)



【Fig. 2】

(a)



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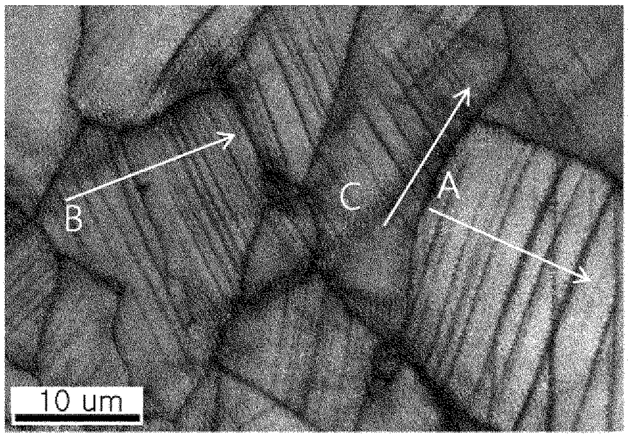
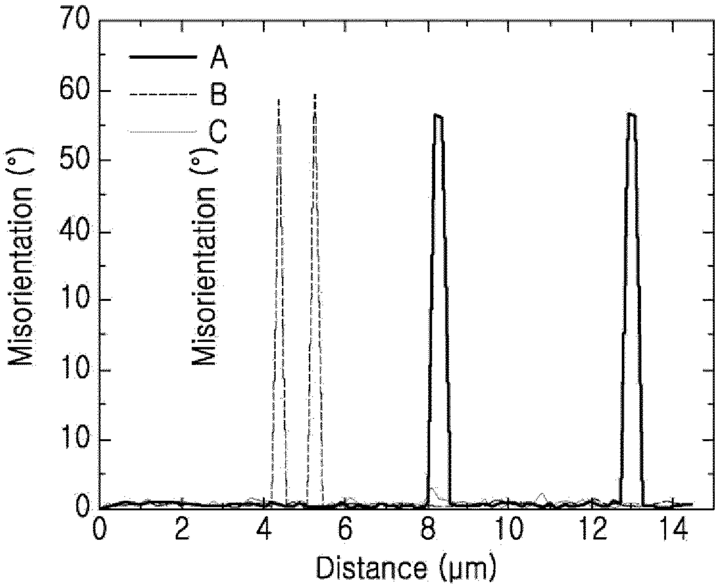

B
C
A
10 um

(c)


A
B
C
Misorientation (°)
Misorientation (°)
70
60
50
40
10
10
10
0
0
2
4
6
8
10
12
14
Distance (μm)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2019/014175

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/38(2006.01)i, C22C 38/32(2006.01)i, C22C 38/02(2006.01)i, C22C 38/06(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 38/38; C21D 8/02; C22C 38/00; C22C 38/04; C23C 2/06; C22C 38/32; C22C 38/02; C22C 38/06

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: austenite, high manganese, yield strength, ductility, grain boundary, reduction

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 10-0851158 B1 (POSCO) 08 August 2008 See paragraphs [0039]-[0041], [0046], [0057]-[0059] and claims 1, 4.	1,5-8,12
Y		2-4,9-11
Y	KR 10-0742823 B1 (POSCO) 25 July 2007 See claims 1, 3, 9.	2-4,9-11
A	KR 10-2010-0118238 A (INDUSTRY-ACADEMIC COOPERATION FOUNDATION, YONSEI UNIVERSITY) 05 November 2010 See claims 1-3, 8-10.	1-12
A	US 2011-0308673 A1 (SCHNEIDER et al.) 22 December 2011 See paragraphs [0050]-[0052] and claims 1-24.	1-12
A	JP 62-270721 A (KOBE STEEL LTD.) 25 November 1987 See pages 2-4.	1-12

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

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

Date of the actual completion of the international search	Date of mailing of the international search report
23 JANUARY 2020 (23.01.2020)	**23 JANUARY 2020 (23.01.2020)**

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2019/014175

Patent document cited in search report	Publication date	Patent family member	Publication date
KR 10-0851158 B1	08/08/2008	CN 101432456 A	13/05/2009
		EP 2097548 A1	09/09/2009
		JP 2009-545676 A	24/12/2009
		JP 5393459 B2	22/01/2014
		KR 10-2008-0060982 A	02/07/2008
		US 2009-0074605 A1	19/03/2009
		WO 2008-078940 A1	03/07/2008
KR 10-0742823 B1	25/07/2007	CN 101346480 A	14/01/2009
		EP 1979500 A1	15/10/2008
		EP 1979500 B1	29/02/2012
		EP 1979500 B9	20/06/2012
		JP 2009-521602 A	04/06/2009
		JP 4958182 B2	20/06/2012
		KR 10-2007-0067950 A	29/06/2007
		MX 2008008296 A	04/03/2009
		US 2009-0202382 A1	13/08/2009
		US 2015-0266519 A1	24/09/2015
		US 8999085 B2	07/04/2015
		WO 2007-075006 A1	05/07/2007
KR 10-2010-0118238 A	05/11/2010	CN 102439188 A	02/05/2012
		EP 2431492 A2	21/03/2012
		EP 2431492 B1	30/09/2015
		JP 2012-525500 A	22/10/2012
		JP 5437482 B2	12/03/2014
		KR 10-1140931 B1	03/05/2012
		KR 10-1193718 B1	22/10/2012
		KR 10-2011-0107473 A	04/10/2011
		US 2012-0045358 A1	23/02/2012
		WO 2010-126268 A2	04/11/2010
		WO 2010-126268 A3	03/03/2011
US 2011-0308673 A1	22/12/2011	CN 102216474 A	12/10/2011
		CN 102216474 B	20/08/2014
		DE 102008056844 A1	02/06/2010
		EP 2366035 A1	21/09/2011
		EP 2366035 B1	05/07/2017
		ES 2642891 T3	20/11/2017
		KR 10-1387040 B1	18/04/2014
		KR 10-2011-0083735 A	20/07/2011
		US 9677146 B2	13/06/2017
		WO 2010-054813 A1	20/05/2010
JP 62-270721 A	25/11/1987	JP 06-019110 B2	16/03/1994

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- KR 1020150075324 **[0005]**