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(54) AUSTENITIC STEEL MATERIAL HAVING EXCELLENT HYDROGEN-EMBRITTLEMENT RESISTANCE

AUSTENITISCHES STAHLMATERIAL MIT HERVORRAGENDER BESTÄNDIGKEIT GEGEN WASSERSTOFFVERSPRÖDUNG

MATÉRIAU EN ACIER AUSTÉNITIQUE PRÉSENTANT UNE EXCELLENTE RÉSISTANCE À LA FRAGILISATION PAR L'HYDROGÈNE

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Description

[Technical Field]

[0001] The present invention relates to an austenitic steel material having high hydrogen-embrittlement resistance, and more particularly, to an austenitic steel material having high hydrogen-embrittlement resistance and suitable for applications such as high-pressure hydrogen gas tanks, pipes, and transfer facilities.

[Background Art]

[0002] Many efforts have been made to reduce environmental pollutants and greenhouse gas emissions for the prevention of global warming and environmental pollution. Thereamong, a technology using hydrogen as an energy source has made a great deal of progress in recent years. Unlike fossil fuels such as coal and petroleum, hydrogen, the most environmentally friendly energy source, is attracting attention as a novel energy source for the future with little emission of pollutants. In particular, there is great interest in hydrogen as a fuel for hydrogen vehicles using fuel cells.

[0003] Hydrogen vehicles, including high-pressure gas containers for storing hydrogen compressed to high pressure, are the most common type of hydrogen vehicles, and such containers are required to have high strength for durability against high pressure, low hydrogen permeability for minimizing the loss of hydrogen caused by the penetration of hydrogen, and high hydrogen-embrittlement resistance for preventing embrittlement caused by hydrogen permeation.

[0004] Basically, hydrogen storage containers and facilities are aimed at reducing storage loss caused by penetration of hydrogen, and thus face centered cubic (FCC)-structure materials having high hydrogen permeability may be suitable therefor. A representative FCC-structure material used for these applications is Cr-Ni-based austenitic stainless steel. Such austenitic stainless steels are used as materials for high-pressure gas containers or liners and pipes of high-pressure gas containers owing to their high hydrogen-embrittlement resistance under high-pressure hydrogen gas environments.

[0005] In recent years, however, hydrogen gas is used at high pressures on the level of tens or hundreds of megapascals (MPa) for enabling long-distance driving and the storage of a large amount of hydrogen through a single operation of charging hydrogen. Therefore, in the case of using austenitic stainless steels having ordinary strength, a large thickness is required to withstand loads under high-pressure conditions, and thus, it may be difficult to avoid an increase in the weight and size of containers or facilities, thereby limiting commercialization thereof.

[0006] As a technique for solving these problems, Japanese Patent Application Laid-open Publication No. H5-98391 and International Patent Publication No. 2014-111285 disclose a technique of increasing the strength of austenitic stainless steel by cold working. However, when strength is increased by cold working, ductility and toughness decrease, and the stability of austenite decreases, thereby causing the formation of strain-induced martensite. Thus, this technique is not suitable for hydrogen containers. In addition, Korean Patent Application Laid-Open Publication No. 10-2006-0018250 discloses a technique of securing the stability of austenite by performing a cold working process twice in different directions. According to the technique, however, chromium (Cr) and nickel (Ni), expensive alloying elements, are added in large amounts to increase the stability of austenite, thereby incurring high costs.

[0007] In addition, Korean Patent Application Laid-Open Publication No. 10-2011-0004491 and Korean Patent Application Laid-Open Publication No. 10-2013-0045931 disclose a technique of guaranteeing the formation of stable austenite and thus improving the hydrogen-embrittlement resistance of austenitic stainless steel by replacing nickel (Ni), an expensive alloying element, with manganese (Mn), an inexpensive alloying element. However, since this technique still uses a large amount of an expensive alloying element, commercialization of the technique is limited in terms of economical aspects.

[0008] JP H04 259325 A discloses a thin hot rolled steel sheet comprising by mass, C: 1.0% or less, Si: 0.01 to 2.50%, Mn: 10 to 30%, Al: 0.001 to 0.10%, P: 0.05% or less, S: 0.05% or less and a remainder of iron and unavoidable impurities.

[0009] EP 2 554 699 A1 discloses a steel sheet comprising by mass, C: 0.5 to 1.5%, Si: 0.1% or less, Mn: 10 to 25%, P: 0.1% or less, S: 0.05% or less, Al: 0.1% or less, Ni: 3.0 to 8.0%, Mo: 0.1% or less, N: 0.01% or less and a remainder of iron and inevitable impurities.

[0010] EP 1 427 866 A1 discloses a method for making a welded tube comprising a casting step, a hot-rolling step, a coiling step, a scouring step, a forming step, a welding step and a final drawing or hydroforming step.

[Disclosure]

[Technical Problem]

[0011] An aspect of the present invention may provide an austenitic steel material having high hydrogen-embrittlement resistance without expensive alloying elements.

[Technical Solution]

[0012] According to an aspect of the present invention, an austenitic steel material having high hydrogen-embrittlement resistance includes, by wt%, carbon (C): 0.1% to 0.5%, copper (Cu): 0.5% to 3.5% or less, nitrogen (N): more than 0% but less than or equal to 1%, manganese (Mn): [Mn]≥-10.7[C]+24.5, chromium (Cr): 10% or less, nickel (Ni): 5% or less, molybdenum (Mo): 5% or less, silicon (Si): 4% or less, aluminum (Al): 5% or less, and a balance of iron (Fe) and inevitable impurities, wherein the austenitic steel material has a $T\text{-}El_2/T\text{-}El_1$ ratio of 0.5 or greater, wherein $T\text{-}El_2$ is an elongation at break in a tensile test performed under high-pressure hydrogen conditions of 25°C and 70 MPa, and $T\text{-}El_1$ is an elongation at break in a tensile test performed under atmospheric conditions of 25°C and 1 atm, and wherein the austenitic steel material has stacking fault energy (SFE) defined by Formula 1 below within a range of 30 mJ/m^2 or greater,

[Formula 1]

$$SFE(mJ/m^2) = 1.6[Ni] - 1.3[Mn] + 0.06[Mn]^2 - 1.7[Cr] + 0.01[Cr]^2 + 15[Mo] - 5.6[Si] + 1.6[Cu] + 5.5[Al] - 60([C] + 1.2[N])^{1/2} + 26.3([C] + 1.2[N])([Cr] + [Mn] + [Mo])^{1/2} + 0.6\{[Ni]([Cr] + [Mn])\}^{1/2}$$

wherein each of [Ni], [Mn], [Cr], [Mo], [Si], [Cu], [Al], [C], and [N] refers to a content in wt% of a corresponding element, wherein the austenitic steel material has a microstructure comprising austenite in an area fraction of 95 to 100%.

[Advantageous Effects]

[0013] One of various effects of the present invention is that the austenitic steel material of the present invention has high hydrogen-embrittlement resistance without expensive alloying elements.

[Description of Drawings]

[0014]

FIG. 1 is a graph illustrating carbon and manganese content ranges according to the present invention.

FIG. 2 is an image of a fracture surface of a specimen of Non-claimed Example 1 after a room-temperature tensile test.

[Best Mode]

[0015] Containers for storing and transferring hydrogen are basically required to have low hydrogen permeability, and thus it is needed to guarantee the formation of an FCC structure having low hydrogen permeability in the case of steel materials for hydrogen containers. In particular, it is necessary to stably maintain the FCC structure in spite of externally-caused deformation such as deformation caused by plastic working or plastic deformation caused by an external load applied during use.

[0016] Furthermore, in recent years, attempts have been constantly made to address the above-described economical demerits of austenitic stainless steels, existing steel materials having high hydrogen-embrittlement resistance, by replacing expensive nickel with inexpensive manganese and adding carbon to stabilize austenite at room temperature. However, in such high-carbon, high-manganese austenitic steel materials, planar slips easily occur because partial dislocations easily develop owing to low stacking fault energy, and thus dislocations easily accumulate on slip planes to result in high work hardening. In addition, the addition of carbon for stabilizing austenite induces dynamic strain aging and thus markedly improves work hardening of the steel materials. Therefore, such high-carbon, high-manganese austenitic steel materials are not suitable for applications requiring hydrogen-embrittlement resistance.

[0017] Thus, the inventors have tried to improve the hydrogen-embrittlement resistance of steel materials by properly adjusting a relationship between carbon and manganese while relatively decreasing the content of carbon, and as a result, the inventors have invented the present invention.

[0018] Hereinafter, an austenitic steel material having high hydrogen-embrittlement resistance will be described in detail, according to an aspect of the present disclosure.

[0019] First, alloying elements of the austenitic steel material and the content ranges of the alloying elements will be

described in detail. In the following description, the content of each element is given in wt% unless otherwise mentioned.

Carbon (C): 0.1% to 0.5%

[0020] Carbon (C) is an element stabilizing austenite and increasing the strength of the steel material. Particularly, carbon (C) decreases transformation points Ms and Md at which austenite transforms into ε-martensite or α-martensite during a cooling or processing process. If the content of carbon (C) is insufficient, the stability of austenite is insufficient, and austenite easily undergoes strain-induced transformation into ε-martensite or α-martensite by external stress. Therefore, an FCC structure may not be maintained, and thus hydrogen-embrittlement resistance may markedly decrease. Therefore, according to the present invention, the content of carbon (C) is within the range of 0.1% or greater, preferably within the range of 0.15% or greater, and even more preferably within the range of 0.2% or greater. However, if the content of carbon (C) is excessively high, dislocations and dynamic strain aging may occur to result in an increase in the work hardening of the steel material and a decrease in the hydrogen-embrittlement resistance of the steel material, and carbides may easily precipitate to result in a decrease in the ductility or toughness of the steel material. Therefore, according to the present invention, the content of carbon (C) is adjusted to be within the range of 0.5% or less, and preferably within the range of 0.45% or less.

Manganese (Mn): $[Mn] \geq -10.7[C]+24.5$ (where each of [Mn] and [C] refers to the weight percent (wt%) of a corresponding element)

[0021] In the present invention, the content of manganese (Mn) is determined by considering a relationship with carbon (C) and other alloying elements. FIG. 1 illustrates a manganese content range for improving hydrogen-embrittlement resistance by stably guaranteeing austenite or ε-martensite having low hydrogen permeability after a room-temperature tensile test. The graph of FIG. 1 shows results that the inventors have obtained through various experiments.

[0022] That is, to obtain a microstructure having high hydrogen-embrittlement resistance before and after a tensile test, the content of manganese (Mn) is adjusted to be within the range of $-10.7[C]+24.5(\%)$ or greater on the condition that the contents of the other elements are within ranges proposed in the present invention. If the content of manganese (Mn) is less than $-10.7[C]+24.5(\%)$, the stability of austenite may decrease, and thus a BCC-based microstructure may be formed by deformation, thereby decreasing hydrogen-embrittlement resistance.

Copper (Cu): 0.5% to 3.5%

[0023] Copper (Cu) stabilizes austenite guaranteeing hydrogen-embrittlement resistance and facilitates slipping by increasing stacking fault energy. If the content of carbon (C) is high, since copper (Cu) has very low solid solubility in carbides and diffuses slowly in austenite, copper (Cu) concentrates along boundaries of carbide nuclei formed in austenite, thereby suppressing the diffusion of carbon (C) and effectively retarding the growth of carbides. As a result, copper (Cu) suppresses the formation of carbides. Owing to this suppression of carbide formation, sites to which carbon (C) diffuses are decreased, thereby improving the hydrogen-embrittlement resistance of the steel material and the ductility and toughness of the steel material as well. In the present invention, if the content of copper (Cu) is 0.5% or greater, this effect of suppressing the formation of carbides may be sufficiently obtained. However, if the content of copper (Cu) is excessively high, the hot workability of the steel material may deteriorate. Therefore, according to the present invention, the content of copper (Cu) also is adjusted to be within the range of 3.5% or less.

Nitrogen (N): 1% or less (excluding 0%)

[0024] Like carbon (C), nitrogen (N) is an element stabilizing austenite and thus improving the toughness of the steel material. Particularly, like carbon (C), nitrogen (N) is very effective in improving the strength of the steel material by the effect of solid solution strengthening. Moreover, as illustrated in Formula 1, nitrogen (N) is known as an element effectively increasing stacking fault energy and thus promoting slipping. In the present invention, however, intended properties may be obtained without great difficulties even when nitrogen (N) is not added. Conversely, if the content of nitrogen (N) is excessively high, coarse nitrides may be formed, and thus the surface quality and properties of the steel material may deteriorate. Thus, the content of nitrogen (N) is adjusted to be within the range of 1% or less, and preferably within the range of 0.5% or less.

[0025] In addition to the above-described elements, the austenitic steel material of the present invention may further include chromium (Cr), nickel (Ni), molybdenum (Mo), silicon (Si), and aluminum (Al).

Chromium (Cr): 10% or less

[0026] When the content of chromium (Cr) is within a proper range, chromium (Cr) increases hydrogen-embrittlement resistance by stabilizing austenite, and increases the strength of the steel material dissolved in austenite. Furthermore, chromium (Cr) is an element improving the corrosion resistance of the steel material. In the present invention, however, intended properties may be obtained without great difficulties even when chromium (Cr) is not added. In addition, since chromium (Cr) is a carbide forming element, if the content of chromium (Cr) is excessively high, carbides may be formed along austenite grain boundaries. Therefore, sites facilitating hydrogen diffusion may be provided, and the toughness of the steel material may decrease. Therefore, according to the present invention, the content of chromium (Cr) is adjusted to be within the range of 10% or less, and preferably within the range of 8% or less.

Nickel (Ni): 5% or less

[0027] Nickel (Ni) is an element very effective in stabilizing austenite. Particularly, nickel (Ni) decreases transformation points Ms and Md at which austenite transforms into ε-martensite or α-martensite during a cooling or processing process. Moreover, as illustrated in Formula 1, nickel (Ni) is known as an element effectively increasing stacking fault energy and thus promoting slipping. In the present invention, however, intended properties may be obtained without great difficulties even when nickel (Ni) is not added. Since nickel (Ni) is an expensive element, if the content of nickel (Ni) is excessively high, the economical feasibility of the steel material decreases. Therefore, according to the present invention, the content of nickel (Ni) is within the range of 5% or less.

Molybdenum (Mo): 5% or less

[0028] If molybdenum (Mo) is added to the steel material in an appropriate amount, molybdenum (Mo) stabilizes austenite and improves the hydrogen-embrittlement resistance of the steel material by decreasing transformation points Ms and Md at which austenite transforms into ε-martensite or α-martensite during a cooling or processing process. In addition, molybdenum (Mo) dissolves in the steel material and improves the strength of the steel material. In addition, molybdenum (Mo) segregates along grain boundaries of austenite, thereby improving the stability of grain boundaries and decreasing the energy of grain boundaries. As a result, molybdenum (Mo) suppresses the precipitation of carbides along grain boundaries. Moreover, as illustrated in Formula 1, molybdenum (Mo) is known as an element effectively increasing stacking fault energy and thus promoting slipping. In the present invention, however, intended properties may be obtained without great difficulties even when molybdenum (Mo) is not added. Since molybdenum (Mo) is an expensive element, if the content of molybdenum (Mo) is excessively high, the economical feasibility of the steel material decreases. Therefore, according to the present invention, the content of molybdenum (Mo) is adjusted to be within the range of 5% or less, and preferably, within the range of 4% or less.

Silicon (Si): 4% or less

[0029] Silicon (Si) improves the castability of molten steel. In particular, silicon (Si), added to the austenitic steel material, dissolves in the austenitic steel material and effectively increases the strength of the austenitic steel material. In the present invention, however, intended properties may be obtained without great difficulties even when silicon (Si) is not added. If the content of silicon (Si) is excessively high, stacking fault energy decreases, thereby causing partial dislocations and concentration of stress and thus decreasing the hydrogen-embrittlement resistance of the steel material. Therefore, according to the present invention, the content of silicon (Si) is within the range of 4% or less.

Aluminum (Al): 5% or less

[0030] If aluminum (Al) is added to the steel material in an appropriate amount, aluminum (Al) stabilizes austenite and improves the hydrogen-embrittlement resistance of the steel material by decreasing transformation points Ms and Md at which austenite transforms into ε-martensite or α-martensite during a cooling or processing process. In addition, aluminum (Al) dissolves in the steel material and increases the strength of the steel material. In addition, aluminum (Al) affects the mobility of carbon (C) in the steel material and effectively suppresses the formation of carbides, thereby increasing the toughness of the steel material. In addition, aluminum (Al) induces cross slips by markedly increasing stacking fault energy, and suppresses partial dislocations and thus decreases concentration of stress, thereby increasing hydrogen-embrittlement resistance. In the present invention, however, intended properties may be obtained without great difficulties even when aluminum (Al) is not added. Preferably, aluminum (Al) may be added in an amount of 0.2% or greater so as to further improve hydrogen-embrittlement resistance. Conversely, if the content of aluminum (Al) is excessively high, the castability and surface quality of steel may deteriorate because of the formation of oxides and

nitrides. Thus, the content of aluminum (Al) is adjusted to be within the range of 5% or less.

[0031] The other element of the austenitic steel material is iron (Fe). However, impurities of raw materials or manufacturing environments may be inevitably included in the austenitic steel material, and such impurities may not be removed from the austenitic steel material. Such impurities are well-known to those of ordinary skill in the art, and thus descriptions thereof will not be given in the present invention. The austenitic steel material of the present invention has stacking fault energy (SFE) expressed by Formula 1 below within the range of 30 mJ/m^2 or greater.

[Formula 1]

$$SFE(mJ/m^2) = 1.6[Ni] - 1.3[Mn] + 0.06[Mn]^2 - 1.7[Cr] + 0.01[Cr]^2 + 15[Mo] - 5.6[Si] + 1.6[Cu] + 5.5[Al] - 60([C] + 1.2[N])^{1/2} + 26.3([C] + 1.2[N])([Cr] + [Mn] + [Mo])^{1/2} + 0.6\{[Ni]([Cr] + [Mn])\}^{1/2}$$

(where each of [Ni], [Mn], [Cr], [Mo], [Si], [Cu], [Al], [C], and [N] refers to the content (wt%) of a corresponding element).

[0032] In general, high-manganese steels having a high manganese content like the austenitic steel material of the present invention have relatively low stacking fault energy compared to general carbon steels and thus easily have partial dislocations, and since slipping of such partial dislocations is limited to particular slip planes, dislocation accumulation and stress concentration are easily caused. Such concentration of stress facilitates diffusion of hydrogen, and thus a phenomenon in which the fracture strength of a material decreases because of diffusion of hydrogen, that is, embrittlement caused by hydrogen, is likely to occur in high-manganese steels like the austenitic steel material of the present invention. Therefore, according to the present invention, the deformation behavior of the austenitic steel material is particularly controlled by adjusting stacking fault energy through control of alloying elements and contents thereof. Based on results of research conducted by the inventors, the inventors have found that if stacking fault energy defined by Formula 1 above is adjusted to be 30 mJ/m^2 or greater, the possibility of hydrogen embrittlement is markedly reduced.

[0033] The degree of work hardening of a steel material caused by concentration of stress may be measured by measuring a strain hardening rate in a tensile test. For example, the austenitic steel material of the present invention may have a strain hardening rate of 14000 N/mm^2 or less in a tensile test performed under atmospheric conditions of 25°C and 1 atm. The strain hardening rate may be calculated from true strain and true stress. If the strain hardening rate in a tensile test is greater than 14000 N/mm^2, concentration of stress caused by dislocations is excessively high, and thus hydrogen easily diffuses and accumulates. Thus, hydrogen embrittlement may occur.

[0034] For example, the austenitic steel material of the present invention may have a tensile strength of 800 MPa or less in a tensile test performed under atmospheric conditions of 25°C and 1 atm. If the tensile strength of the austenitic steel material is greater than 800 MPa, hydrogen-embrittlement resistance may deteriorate because of high work hardening caused by concentration of stress.

[0035] The austenitic steel material of the present invention has a microstructure including austenite in an area fraction of 95% or greater. If the area fraction of austenite is less than 95%, intended hydrogen-embrittlement resistance may not be obtained.

[0036] For example, the microstructure of the austenitic steel material of the present disclosure may be austenite, or ε-martensite and austenite after a tensile test performed under atmospheric conditions of 25°C and 1 atm. If the microstructure of the austenitic steel material has ferrite, intended hydrogen-embrittlement resistance may not be obtained.

[0037] The austenitic steel material of the present invention may be manufactured by a general steel material manufacturing method using a steel slab having the above-described composition. For example, the austenitic steel material of the present invention may be manufactured by reheating, rough rolling, finish rolling, and cooling a steel slab having the above-described composition.

[0038] In this case, the temperature of the finish rolling process may be adjusted to be greater than a non-crystallization temperature. If the finish rolling process is performed at a temperature equal to or lower than the non-crystallization temperature, the strength of the steel material may be excessively high due to excessive formation and accumulation of dislocations, thereby promoting concentration of stress and fracture caused by hydrogen. In addition, ferrite inducing hydrogen embrittlement during tensile deformation may be early formed, and thus it may be difficult to obtain intended hydrogen-embrittlement resistance.

[0039] In addition, the steel material may be cooled through an accelerated cooling process after a rolling process, so as to suppress the formation of carbides. The reason for this is that if carbides are formed, the elongation of the steel material decreases, and in particular, hydrogen accumulates along boundaries between carbides and austenite, thereby decreasing hydrogen-embrittlement resistance. Since elements such as carbon (C), chromium (Cr), and molybdenum (Mo) are main carbide forming elements, whether or not to perform accelerated cooling and the rate of accelerated

cooling are determined according to the contents of such elements as expressed by the following formula.

[Formula 2]

$$\text{Cooling rate } (°C/s) \geq 15[C] + [Cr] + [Mo]$$

(where each of [C], [Cr], and [Mo] refers to the content (wt%) of a corresponding element).

[Mode for Invention]

[0040] Hereinafter, the present invention will be described more specifically through examples. However, the following examples are for illustrative purposes only and are not intended to limit the scope of the present invention. The scope of the present invention is defined by the appended claims.

[0041] Slabs having compositions shown in Table 1 below were prepared, and then rolled materials were manufactured by hot rolling and cooling the slabs. At that time, the same process conditions were applied to all the examples except finish rolling temperatures and cooling rates as shown in Table 2 below. Referring to Table 2, a cooling rate in Comparative Example 5 is not stated, and this means that simple air cooling was performed.

[0042] Thereafter, microstructures of the rolled materials were observed, and the fraction of austenite in each of the rolled materials was measured. Then, a tensile test was performed on the rolled materials under atmospheric conditions of 25°C and 1 atm, and then the tensile strength, strain hardening rate, elongation at break T-El$_1$, and ferrite fraction of each of the rolled materials were measured. Independently of this, a tensile test was performed on the rolled materials under high-pressure hydrogen conditions of 25°C and 70 MPa, and elongation at break T-El$_2$ was measured. Results thereof are shown in Table 3 below.

[Table 1]

No.	Alloying composition (wt%)									□① (wt%)
	C	Mn	Cu	N	Cr	Ni	Mo	Si	Al	
*CE1	0.62	18.2	0.06	0.012	0.13					17.866
CE2	0.46	16	0.13	0.021		0.2				19.578
CE3	0.42	23.2	5.32	0.016					1.52	20.006
CE4	0.83	15.2	0.32	0.017	5.3			0.32		15.619
CE5	0.13	19.5		0.021			0.2			23.109
***NCE1	0.41	31.8		0.015					1.72	20.113
**IE2	0.29	29.8	0.35	0.022					0.86	21.397
IE3	0.42	27.3	0.51	0.022		2.08			1.51	20.006
***NCE4	0.28	31.2		0.022	1.08	1.75			0.35	21.504
IE5	0.38	28.5	1.1	0.018			0.16	0.31	1.74	20.434
where □① refers to -10.7C (wt%) + 24.5										
*CE: Comparative Example, **IE: Inventive Example ***NC: Non-claimed Example										

[Table 2]

No.	Finish rolling temperature (°C)	Cooling rate (°C/sec)
Comparative Example 1	910	11.5
Comparative Example 2	870	5.6
Comparative Example 3	865	7.2
Comparative Example 4	892	15.2

(continued)

No.	Finish rolling temperature (°C)	Cooling rate (°C/sec)
Comparative Example 5	856	-
Non-claimed Example 1	912	15.4
Inventive Example 2	905	12.7
Inventive Example 3	922	13.6
Non-claimed Example 4	915	20.4
Inventive Example 5	932	15.6

[Table 3]

No.	Stacking fault energy (mJ/m^2)	Before tensile test	After tensile test			elongation at break ratio
		Austenite fraction (area%)	Ferrite fraction (area%)	Tensile strength (MPa)	Strain hardening rate (N/mm^2)	
*CE1	19.7	100	0	1015	18653	0.1
CE2	5.5	96	12	948	19320	0.13
CE3	34.9	100	Not measured (cracks)			
CE4	30.0	92.5	0	1135	21396	0.07
CE5	-5.1	62	28	832	17504	0.08
***NCE 1	53.0	100	0	760	9854	0.75
**IE2	31.5	100	0	658	4850	0.97
IE3	42.9	100	0	715	6512	0.91
***NCE 4	33.3	100	0	672	4385	0.96
IE5	42.2	100	0	675	5214	0.92
*CE: Comparative Example, **IE: Inventive Example ***: Non-claimed Example						

[0043] Referring to Table 3, after tensile deformation at room temperature, each of Inventive Examples 2, 3 and 5 satisfying the composition ranges proposed in the present invention had stable austenite without ferrite, a low strain hardening rate, and low tensile strength. In particular, since Inventive Examples 2, 3 and 5 were rolled at a finish rolling temperature higher than a non-crystallization temperature, the formation and accumulation of dislocations were suppressed, and since Inventive Examples 1 to 5 were cooled at a cooling rate satisfying the range proposed in the present invention, the formation of carbides was effectively suppressed. As a result, austenitic steel materials having high hydrogen-embrittlement resistance, that is, having a high elongation at break ratio, could be obtained.

[0044] However, Comparative Example 1 had carbon and manganese contents outside the ranges proposed in the present invention and particularly, a high strain hardening rate because of an excessively high carbon content, and thus, the elongation at break ratio of Comparative Example 1 was low. That is, Comparative Example 1 had poor hydrogen-embrittlement resistance.

[0045] Particularly, in Comparative Example 2 having a manganese content outside of the range proposed in the present invention, austenite was unstable, and thus ferrite susceptible to hydrogen embrittlement was formed after tensile deformation. That is, Comparative Example 2 had poor hydrogen-embrittlement resistance.

[0046] In Comparative Example 3 having carbon and manganese contents and stacking fault energy within the ranges proposed in the present disclosure but a copper content greater than the range proposed in the present invention, cracks

were formed in the rolled material, and thus a normal specimen could not obtained.

[0047] Since Comparative Example 4 had a carbon content greater than the range proposed in the present invention, Comparative Example 4 had a high strain hardening rate and carbides excessively precipitated along austenite grain boundaries, and thus the hydrogen-embrittlement resistance of Comparative Example 4 was poor.

[0048] In addition, since Comparative Example 5 had a manganese content outside the range proposed in the present invention, an intended microstructure could not be obtained, and thus the hydrogen-embrittlement resistance of Comparative Example 5 was poor.

[0049] FIG. 2 is an image of a fracture surface of a specimen of Non-claimed Example 1 after the room-temperature specimen of Inventive Example 1 after the room-temperature tensile test. Referring to FIG. 2, fracture occurred in a dimple type which is typical of ductile fracture.

[0050] While exemplary embodiments have been shown and described above, it will be apparent to those skilled in the art that modifications and other embodiments could be made therefrom. That is, such modifications and other embodiments could be made without departing from the scope of the present invention as defined by the appended claims.

Claims

1. An austenitic steel material having high hydrogen-embrittlement resistance, the austenitic steel material comprising, by wt%, carbon (C): 0.1% to 0.5%, copper (Cu): 0.5% to 3.5% or less, nitrogen (N): more than 0% but less than or equal to 1%, manganese (Mn): [Mn]≥-10.7[C]+24.5 where each of [Mn] and [C] refers to a weight percent (wt%) of a corresponding element, chromium (Cr): 10% or less, nickel (Ni): 5% or less, molybdenum (Mo): 5% or less, silicon (Si): 4% or less, aluminum (Al): 5% or less, and a balance of iron (Fe) and inevitable impurities,
wherein the austenitic steel material has a $T\text{-}El_2/T\text{-}El_1$ ratio of 0.5 or greater, where $T\text{-}El_2$ is an elongation at break in a tensile test performed under hydrogen conditions of 25°C and 70 MPa, and $T\text{-}El_1$ is an elongation at break in a tensile test performed under atmospheric conditions of 25°C and 1 atm, and
wherein the austenitic steel material has stacking fault energy (SFE) defined by Formula 1 below within a range of 30 mJ/m^2 or greater,

[Formula 1]

$$SFE(mJ/m^2) = 1.6[Ni] - 1.3[Mn] + 0.06[Mn]^2 - 1.7[Cr] + 0.01[Cr]^2 + 15[Mo] - 5.6[Si] + 1.6[Cu] + 5.5[Al] - 60([C] + 1.2[N])^{1/2} + 26.3([C] + 1.2[N])([Cr] + [Mn] + [Mo])^{1/2} + 0.6\{[Ni]([Cr] + [Mn])\}^{1/2}$$

wherein each of [Ni], [Mn], [Cr], [Mo], [Si], [Cu], [Al], [C], and [N] refers to a content in wt% of a corresponding element, wherein the austenitic steel material has a microstructure comprising austenite in an area fraction of 95 to 100%.

2. The austenitic steel material of claim 1, wherein the austenitic steel material has a strain hardening rate of 14000 N/mm^2 or less in the tensile test performed under the atmospheric conditions of 25°C and 1 atm.

3. The austenitic steel material of claim 1, wherein the austenitic steel material has a tensile strength of 800 MPa or less in the tensile test performed under the atmospheric conditions of 25°C and 1 atm.

4. The austenitic steel material of claim 1, wherein after the tensile test performed under the atmospheric conditions of 25°C and 1 atm, the austenitic steel material has a microstructure formed of austenite, or formed of ε-martensite and austenite.

Patentansprüche

1. Austenitisches Stahlmaterial mit hoher Wasserstoffversprödungsbeständigkeit, wobei das austenitische Stahlmaterial in Gew.-% Kohlenstoff (C): 0,1 % bis 0,5 %, Kupfer (Cu): 0,5 % bis 3,5 % oder weniger, Stickstoff (N): mehr als 0 %, aber weniger als oder gleich 1 %, Mangan (Mn): [Mn]≥-10,7[C]+24,5, wobei sich [Mn] und [C] jeweils auf

einen Gewichtsprozentanteil (Gew.-%) des entsprechenden Elements beziehen, Chrom (Cr): 10 % oder weniger, Nickel (Ni): 5 % oder weniger, Molybdän (Mo): 5 % oder weniger, Silicium (Si): 4 % oder weniger, Aluminium (Al): 5 % oder weniger und als Rest Eisen (Fe) und unvermeidliche Verunreinigungen umfasst, wobei das austenitische Stahlmaterial ein $T\text{-}El_2/T\text{-}El_1$-Verhältnis von 0,5 oder mehr aufweist, wobei $T\text{-}El_2$ eine Bruchdehnung in einem Zugversuch ist, durchgeführt unter Wasserstoffbedingungen von 25 °C und 70 MPa, und $T\text{-}El_1$ eine Bruchdehnung in einem Zugversuch ist, durchgeführt unter atmosphärischen Bedingungen von 25 °C und 1 atm, und wobei das austenitische Stahlmaterial eine Stapelfehlerenergie (SFE), definiert durch die unten folgende Formel 1, in einem Bereich von 30 mJ/m^2 oder größer aufweist,

[Formel 1]

$$SFE(mJ/m^2) = 1{,}6[Ni] - 1{,}3[Mn] + 0{,}06[Mn]^2 - 1{,}7[Cr] + 0{,}01[Cr]^2 + 15[Mo] - 5{,}6[Si] + 1{,}6[Cu] + 5{,}5[Al] - 60([C] + 1{,}2[N])^{1/2} + 26{,}3([C] + 1{,}2[N])([Cr] + [Mn] + [Mo])^{1/2} + 0{,}6\{[Ni]([Cr] + [Mn])\}^{1/2}$$

wobei sich [Ni], [Mn], [Cr], [Mo], [Si], [Cu], [Al], [C] und [N] jeweils auf einen Gehalt in Gew.-% eines entsprechenden Elements beziehen, wobei das austenitische Stahlmaterial eine Mikrostruktur aufweist, die Austenit in einem Flächenanteil von 95 bis 100 % umfasst.

2. Austenitisches Stahlmaterial nach Anspruch 1, wobei das austenitische Stahlmaterial bei dem unter atmosphärischen Bedingungen von 25 °C und 1 atm durchgeführten Zugversuch eine Kaltverfestigungsrate von 14000 N/mm^2 oder weniger aufweist.

3. Austenitisches Stahlmaterial nach Anspruch 1, wobei das austenitische Stahlmaterial eine Zugfestigkeit von 800 MPa oder weniger in dem unter den atmosphärischen Bedingungen von 25 °C und 1 atm durchgeführten Zugversuch aufweist.

4. Austenitisches Stahlmaterial nach Anspruch 1, wobei nach dem unter atmosphärischen Bedingungen von 25 °C und 1 atm durchgeführten Zugversuch das austenitische Stahlmaterial eine aus Austenit oder aus ε-Martensit und Austenit gebildete Mikrostruktur aufweist.

Revendications

1. Matériau en acier austénitique présentant une résistance élevée à la fragilisation par l'hydrogène, le matériau en acier austénitique comprenant, en % en poids, du carbone (C) : 0,1 % à 0,5 %, du cuivre (Cu) : 0,5 % à 3,5 % ou moins, de l'azote (N) : supérieur à 0 %, mais inférieur ou égal à 1 %, du manganèse (Mn) : $[Mn] \geq -10{,}7[C] + 24{,}5$ où chacun de [Mn] et de [C] fait référence à un pourcentage en poids (% en poids) d'un élément correspondant, du chrome (Cr) : 10 % ou moins, du nickel (Ni) : 5 % ou moins, du molybdène (Mo) : 5 % ou moins, du silicium (Si) : 4 % ou moins, de l'aluminium (Al) : 5 % ou moins et un complément de fer (Fe) et d'impuretés inévitables, le matériau en acier austénitique présentant un rapport $T\text{-}El_2/T\text{-}EEl_1$ supérieur ou égale à 0,5, où $T\text{-}El_2$ représente un allongement à la rupture dans un test de traction effectué dans des conditions d'hydrogène de 25 °C et 70 MPa et où $T\text{-}El_1$ représente un allongement à la rupture dans un test de traction effectué dans des conditions atmosphériques de 25 °C et 1 atm et le matériau en acier austénitique présentant une énergie de défaut d'empilement (SFE) définie par la formule 1 ci-dessous à l'intérieur d'une plage supérieure ou égale à 30 mJ/m^2,

[Formule 1]

$$SFE(mJ/m^2) = 1{,}6[Ni] - 1{,}3[Mn] + 0{,}06[Mn]^2 - 1{,}7[Cr] + 0{,}01[Cr]^2 + 15[Mo] - 5{,}6[Si] + 1{,}6[Cu] + 5{,}5[A1] - 60([C] + 1{,}2[N])^{1/2} + 26{,}3([C] + 1{,}2[N])([Cr] + [Mn] + [Mo])^{1/2} + 0{,}6\{[Ni]([Cr] + [Mn])\}^{1/2}$$

[Ni], [Mn], [Cr], [Mo], [Si], [Cu], [Al], [C] et [N] correspondant à une teneur en % en poids d'un élément correspondant, le matériau en acier austénitique présentant une microstructure comprenant de l'austénite dans une fraction de

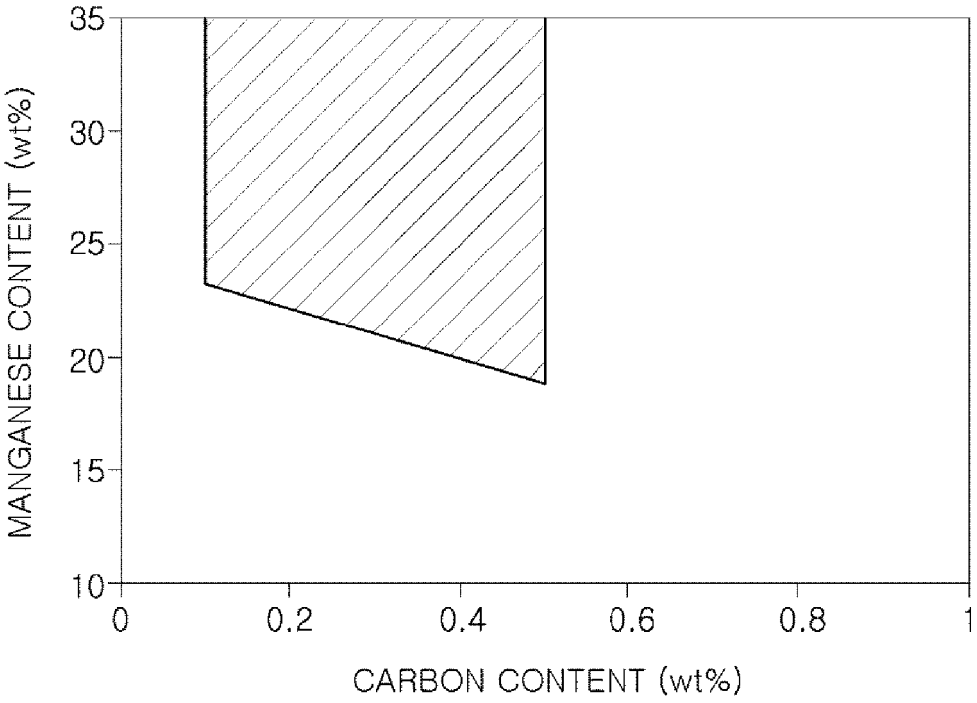
surface de 95 à 100 %.

2. Matériau en acier austénitique selon la revendication 1, dans lequel le matériau en acier austénitique présente une vitesse de durcissement sous contrainte inférieure ou égale à 14 000 N/mm^2 lors du test de traction effectué dans les conditions atmosphériques de 25 °C et 1 atm.

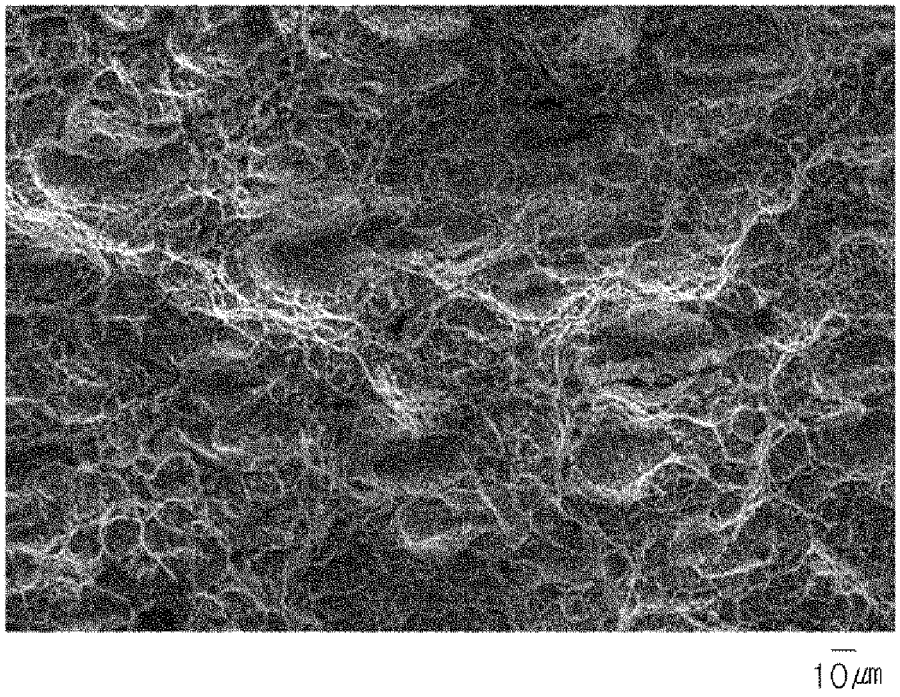
3. Matériau en acier austénitique selon la revendication 1, dans lequel le matériau en acier austénitique présente une force de traction inférieure ou égale à 800 MPa dans le test de traction effectué dans les conditions atmosphériques de 25 °C et 1 atm.

4. Matériau en acier austénitique selon la revendication 1, dans lequel après le test de traction effectué dans les conditions atmosphériques de 25 °C et 1 atm, le matériau en acier austénitique présente une microstructure constituée d'austénite, ou constituée de ε-martensite et d'austénite.

【Figure 1】



【Figure 2】



REFERENCES CITED IN THE DESCRIPTION

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