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

(72) Inventor: **HONG, Soon-Taik**
Pohang-si,
Gyeongsangbuk-do 37877 (KR)

(74) Representative: **Potter Clarkson LLP**
The Belgrave Centre
Talbot Street
Nottingham NG1 5GG (GB)

(54) **STEEL SHEET HAVING EXCELLENT PWHT RESISTANCE FOR LOW-TEMPERATURE PRESSURE VESSEL AND METHOD FOR MANUFACTURING SAME**

(57) The present invention relates to a steel plate having excellent PWHT resistance and low-temperature toughness for a low-temperature pressure vessel and a method for manufacturing the same, wherein the steel plate comprises, in terms of wt%, 0.07-0.17% of C, 0.15-0.40% of Si, 0.3-0.7% of Mn, 0.012% or less of P, 0.015% or less of S, 3.0-4.0% of Ni, 0.03-0.25% of W, and the balance of Fe and inevitable impurities, has a micro-structure comprising 25-80 area% of tempered bainite and the balance of tempered martensite, and has a tensile strength of 600 MPa or more.

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Description

[Technical Field]

[0001] The present disclosure relates to a thick steel plate used in a low-temperature pressure vessel, a ship, a storage tank, a structural steel, and the like, and a method for manufacturing the same, and more particularly, to a steel plate having excellent PWHT resistance and low-temperature toughness for a low-temperature pressure vessel in which a tensile strength is 600 MPa or more, and a method for manufacturing the same.

[Background Art]

[0002] As a thick plate steel material having high strength for low-temperature uses, a mixed structure including ferrite, a martensite structure, and a bainite structure, or a nearly single-phase structure mainly consisting of bainite and ferrite, or the like, is widely known.

[0003] It is necessary to have high strength, since the steel material itself is usable as a structural material at the time of construction. Meanwhile, this high strength structural steel material is required to have excellent PWHT resistance. The high strength hot rolled steel material manufactured through a general normalizing treatment may have a mixed structure of ferrite and pearlite. However, when a PWHT treatment is performed in a subsequent process of a steel material having the structure, a carbide is formed along a grain boundary, and thus, strength and toughness of the steel material are lowered, failing to guarantee physical properties required for PWHT. An example of the conventional technique regarding this is disclosed in Korean Patent Laid-Open Publication No. 2012-0011289.

[0004] The Korean Patent Laid-Open Publication suggests a high strength steel material for LPG having a strength of 500 MPa or more including: in terms of wt%, 0.08-0.15% of C, 0.2-0.3% of Si, 0.5-1.2% of Mn, 0.01-0.02% of P, 0.004-0.006% of S, more than 0%-0.01% or less of Ti, 0.05-0.1% of Mo, 3.0-5.0% of Ni, and a balance of Fe and inevitable impurities, characterized in that Ni and Mo are added to the steel composition component.

[0005] However, since the invention disclosed in the above-described publication is a steel material manufactured through general normalizing, there is a problem in that deterioration of strength and toughness of the steel material after PWHT treatment is not avoidable even in the case that Ni, or the like, is added.

[0006] Therefore, in a thick steel plate having high strength used in a low-temperature pressure vessel, a ship, a storage tank, a structural steel, and the like, there is growing demand for development of a high strength steel material having excellent PWHT resistance for an extended period of time.

[Related Art Document]

[0007] (Patent Document 1) Korean Patent Laid-Open Publication No. 2012-0011289

[Disclosure]

[Technical Problem]

[0008] An aspect of the present disclosure is to provide a steel plate having excellent PWHT resistance for an extended period of time and high strength of a low-temperature pressure vessel by controlling a steel composition, and cooling and heat treatment processes to form a microstructure into a mixed structure of tempered bainite and tempered martensite, and a method for manufacturing the same.

[0009] However, technical problems to be achieved in the present disclosure are not limited to the above mentioned problems, and other non-mentioned problems will be clearly understood by those skilled in the art from the following descriptions.

[Technical Solution]

[0010] According to an aspect of the present disclosure, a steel plate having excellent PWHT resistance for a low-temperature pressure vessel includes: in terms of wt%, 0.07-0.17% of C, 0.15-0.40% of Si, 0.3-0.7% of Mn, 0.012% or less of P, 0.015% or less of S, 3.0-4.0% of Ni, 0.03-0.25% of W, and a balance of Fe and inevitable impurities, wherein the steel plate has a microstructure including 25-80 area% of tempered bainite and a balance of tempered martensite.

[0011] The steel plate may maintain tensile strength at 600 MPa or more even when the steel plate is subjected to PWHT for a maximum of 20 hours at 580-640°C.

[0012] The steel plate may have a Charpy impact energy value of 200J or more at -110°C even when the steel plate is subjected to PWHT for a maximum of 20 hours at 580-640°C.

[0013] According to another aspect of the present disclosure, a method for manufacturing a steel plate having excellent PWHT resistance for a low-temperature pressure vessel includes:

reheating a steel slab at a temperature of 1050-1250°C, the steel slab including, in terms of wt%, 0.07-0.17% of C, 0.15-0.40% of Si, 0.3-0.7% of Mn, 0.012% or less of P, 0.015% or less of S, 3.0-4.0% of Ni, 0.03-0.25% of W, and a balance of Fe and inevitable impurities;
hot rolling the reheated steel slab and terminating the rolling at a temperature of 800°C or more to obtain a hot rolled steel plate;
heating the hot rolled steel plate to 800-950°C, followed by water cooling at a cooling ate of 2.5-30°C/sec; and tempering the water cooled steel plate at 550-660°C for {1.5×t + (10-30) } minutes [wherein t is a thickness (mm) of the steel material].

[0014] The method may further include: a PWHT process for a maximum of 20 hours at 580-640°C after the tempering.
[0015] A steel microstructure obtained by the tempering may have 25-80 area fraction % of tempered bainite and a balance of tempered martensite.

[Advantageous Effects]

[0016] As set forth above, according to an exemplary embodiment in the present disclosure, a steel plate having excellent PWHT resistance for a low-temperature pressure vessel, stably usable at a low temperature of about -110°C while satisfying a tensile strength of 600 MPa or more, may be effective provided.

[Best Mode for Invention]

[0017] Hereinafter, the present disclosure will be described in detail.
[0018] First, a steel plate having excellent PWHT resistance for a low-temperature pressure vessel of the present disclosure is described.
[0019] The steel plate of the present disclosure includes, in terms of wt%, 0.07-0.17% of C, 0.15-0.40% of Si, 0.3-0.7% of Mn, 0.012% or less of P, 0.015% or less of S, 3.0-4.0% of Ni, 0.03-0.25% of W, and a balance of Fe and inevitable impurities, and specific steel composition components and reasons for limiting the components are as follows.
[0020] In the present disclosure, C is preferably limited to a content of 0.07-0.17%. When the content is less than 0.07%, a self-strength of a matrix may be deteriorated. When the content is more than 0.17%, weldability of the steel plate may be greatly deteriorated.
[0021] Si is a component to be added for a deoxidation effect, a solid-solution strengthening effect and an impact transition temperature increasing effect, and is preferably added in a content of 0.15% or more in order to achieve these additive effects. However, when the content of Si is more than 0.40%, the weldability is lowered and an oxide film is excessively formed on a surface of the steel plate, such that the content thereof is preferably limited to 0.15-0.40%.
[0022] Mn forms MnS, a non-metallic inclusion elongated together with S, to lower a room temperature elongation and a low-temperature toughness, such that a content of Mn is preferably controlled to be 0.7% or less. However, due to characteristics of the components of the present disclosure, when the content of Mn is less than 0.3%, it is difficult to ensure adequate strength, such that an added content of Mn is preferably limited to 0.3-0.7%.
[0023] P is an element that deteriorates low-temperature toughness, such that a content of P is preferably suppressed as much as possible. However, since excessive cost is required to remove P in a steelmaking process, the content of P may be controlled within a range of 0.012% or less.
[0024] S is also an element that adversely affects low-temperature toughness together with P, but as similar to P, excessive cost may be required to remove S in a steelmaking process, such that the content of S may be controlled within a range of 0.015% or less.
[0025] Ni is the most effective element for improving low-temperature toughness. However, when an added content of Ni is less than 3.0%, low-temperature toughness may be deteriorated. When the added content is more than 4.0%, production cost may be increased. Therefore, Ni is preferably added within a range of 3.0 to 4.0%.
[0026] In the present disclosure, W is an important element that is solid-solutionized in austenite to increase curing ability of austenite and precipitates into a carbide (W_2C) matched with a matrix to increase a strength of the steel. When W is added in a content of less than 0.03%, an addition effect may not be expected. When W is added in a content of more than 0.25%, a coarse precipitate may be formed during a casting process to deteriorate low-temperature toughness, such that the content of W is preferably limited to 0.03-0.25%.
[0027] Meanwhile, the steel plate of the present disclosure may have a microstructure including 25-80 area% of tempered bainite and a balance of tempered martensite. When a fraction of the tempered bainite is less than 25%, an amount of the tempered martensite may be excessive, and low-temperature toughness of the steel plate may be dete-

riorated. On the other hand, when the fraction of the tempered bainite is more than 80%, it may be difficult to secure desired strength of the steel plate.

[0028] More preferably, the microstructure may include 30-70 area fraction% of tempered bainite and a balance of tempered martensite.

[0029] The steel plate having the above-described steel composition components and microstructure may effectively maintain tensile strength at 600 MPa or more and have excellent low-temperature toughness even when the steel plate is subjected to PWHT for a maximum of 20 hours at 580-640°C.

[0030] Next, a method for manufacturing a steel plate having excellent PWHT resistance for a low-temperature pressure vessel of the present disclosure will be described.

[0031] The method for the steel plate of the present disclosure includes: reheating a steel slab having the above-described steel composition components at 1050-1250°C; hot rolling the reheated steel slab and terminating the rolling at a temperature of 800°C or more to obtain a hot rolled steel plate; heating the hot rolled steel plate to 800-950°C, followed by water cooling at a cooling rate of 2.5-30°C/sec; and tempering the water cooled steel material at 550-660°C for {1.5×t + (10-30)} minutes [wherein t is a thickness (mm) of the steel material] .

[0032] First, in the present disclosure, the steel slab having the steel composition component is reheated at 1050-1250°C. When a reheating temperature is less than 1050°C, a solute atom may be difficult to be solid-solutionized, and when the reheating temperature is more than 1250°C, an austenite crystal grain size may be excessively coarse to lower physical properties of the steel plate.

[0033] Subsequently, in the present disclosure, the reheated steel slab may be hot rolled. Specifically, in the present disclosure, the reheated steel slab may be hot rolled, and the rolling may be terminated at a temperature of 800°C or more. When a hot rolling temperature is less than 800°C, hot deformation resistance may increase at the time of rolling, which may result in a load on a rolling mill.

[0034] A reduction rate per pass in the hot rolling is preferably 5-30%.

[0035] In addition, in the present disclosure, the hot rolled steel plate may be heated at 800-950°C and then water cooled at a cooling rate of 2.5-30°C/sec.

[0036] When a heating temperature is less than 800°C, an alloy component may be difficult to be sufficiently solid-solutionized, and when the heating temperature is more than 950°C, crystal grains may be coarsened, such that the toughness may be deteriorated.

[0037] In addition, when the cooling rate is less than 2.5°C/sec, the martensite structure may not be obtained. On the other hand, when the cooling rate is more than 30°C/sec, since a large amount of cooling water may be required, there is an economic burden of requiring additional cooling equipment, such that the cooling rate is preferably limited to 2.5-30°C/sec.

[0038] Subsequently, in the present disclosure, the water cooled steel plate may be tempered.

[0039] Specifically, in the present disclosure, the water cooled steel plate may be tempered at 550-660°C for {1.5×t + (10-30)} minutes [wherein t is a thickness (mm) of the steel material] . When a tempering temperature is less than 550°C, the toughness may be deteriorated by excessive strength. When the tempering temperature is more than 660°C, strength may be excessively deteriorated.

[0040] Further, in the present disclosure, a tempering time may be determined to {1.5×t + (10-30)} minutes [wherein t is a thickness (mm) of the steel material], and a specific reason for the limitation is as follows.

[0041] In other words, when the tempering time is shorter than the above criteria, the tempered martensite structure may be difficult to be obtained. On the other hand, when the tempering time is longer than the above criteria, overall productivity may be damaged.

[0042] By the tempering heat treatment under the above-described condition, the steel microstructure including 25-80 area% of tempered bainite and a balance of tempered martensite may be obtained.

[0043] More preferably, the microstructure may include 30-70 area fraction% of tempered bainite and a balance of tempered martensite.

[0044] Subsequently, in the present disclosure, PWHT heat treatment may be performed on the tempered steel plate to remove stress of a welded portion after welding for manufacturing a pressure vessel. In other words, a PWHT process for a maximum of 20 hours at 580-640°C may be further included.

[0045] When a PWHT temperature is less than 580°C, it may be difficult to remove residual stress from the welded portion, or the like, and when the PWHT temperature is more than 640°C, strength of the steel material may be significantly lowered. Further, when the PWHT time is more than 20 hours, strength may be excessively deteriorated.

[Mode for Invention]

[0046] Hereinafter, the present disclosure will be described in more detail through Examples.

[0047] Steel slabs having composition components shown in Table 1 below were prepared, respectively, and these steel slabs were reheated at 1100°C. Then, the reheated steel slabs were hot rolled at a reduction rate of 15% per pass, and the hot rolling was terminated at 900°C to manufacture hot rolled steel plates having a predetermined thickness.

[0048] The hot rolled steel plates were heated at an austenitization temperature and water cooled under conditions shown in Table 2 below, and subsequently, tempered at temperature and time shown in Table 2 below. In addition, the tempered steel plates were also subjected to PWHT treatment under the conditions shown in Table 2 below.

[0049] As described above, the PWHT-treated steel plates were evaluated for yield strength, tensile strength and low temperature toughness, and results thereof are also shown in Table 2 below. Meanwhile, in Table 2 below, the low temperature toughness is a result of evaluating a specimen having V notch at -110°C with the Charpy impact energy value obtained by performing the Charpy impact test.

[Table 1]

Kind of steel	Composition component (wt%)						
	C	Mn	Si	P	S	Ni	W
Inventive steel a	0.10	0.62	0.29	0.009	0.0012	3.49	0.08
Inventive steel b	0.09	0.60	0.27	0.008	0.0010	3.45	0.11
Inventive steel c	0.10	0.65	0.28	0.010	0.0011	3.55	0.18
Comparative steel d	0.11	0.68	0.29	0.012	0.0012	3.50	-

[Table 2]

Classification	Kind of steel	Heating temperature (°C)	Water cooling rate (°C/s)	Tempering temperature (°C)	Tempering time (min)	PWHT temperature (°C)	PWHT time (hr)	Temperedbainite area fraction (%)	YS (Mpa)	TS (Mpa)	-110°C Impact toughness (J)
Inventive Example 1	a	850	15.0	650	50	630	15	60	568	608	256
Inventive Example 2		860	8.5	650	90	630	20	55	557	602	251
Inventive Example 3	b	850	15.0	650	50	630	15	53	558	610	227
Inventive Example 4		860	8.5	650	90	630	20	50	557	605	233
Inventive Example 5	c	850	15.0	650	50	630	15	48	560	615	230
Inventive Example 6		850	8.5	650	90	630	20	45	551	610	215
Comparative Example 1	D	850	Air cooling	650	50	630	15	0	458	523	155
Comparative Example 2		850	Air cooling	650	90	630	20	0	442	516	148

[0050] As shown in Tables 1 and 2, it could be appreciated that in Inventive Examples 1-6 in which the steel composition components and the manufacturing process conditions satisfy the range of the present disclosure, after tempering treatment, the structure including 25-80 area fraction% of tempered bainite and a balance of tempered martensite could be obtained, such that as compared to Comparative Examples, yield strength and tensile strength after the subsequent PWHT were higher by about 100 MPa and 80 MPa, respectively, and -110°C low temperature toughness was also higher by 70J or more.

[0051] On the other hand, since the comparative steel d did not contain W, strength of the steel was relatively low. In Comparative Examples 1 and 2, since water cooling was not performed but air cooling was performed, the tempered bainite was not generated, such that the yield strength and tensile strength after the subsequent PWHT were lower than those of the Inventive Example, and the -110°C low temperature toughness was also lower than that of the Inventive Example.

Claims

1. A steel plate having excellent PWHT resistance for a low-temperature pressure vessel comprising:

in terms of wt%, 0.07-0.17% of C, 0.15-0.40% of Si, 0.3-0.7% of Mn, 0.012% or less of P, 0.015% or less of S, 3.0-4.0% of Ni, 0.03-0.25% of W, and a balance of Fe and inevitable impurities,
wherein the steel plate has a steel microstructure including 25-80 area% of tempered bainite and a balance of tempered martensite.

2. The steel plate of claim 1, wherein the steel plate maintains tensile strength at 600 MPa or more even when the steel plate is subjected to PWHT for a maximum of 20 hours at 580-640°C.

3. The steel plate of claim 1, wherein the steel microstructure includes 30-70 area% of tempered bainite and a balance of tempered martensite.

4. The steel plate of claim 1, wherein the steel plate has a Charpy impact energy value of 200J or more at -110°C even when the steel plate is subjected to PWHT for a maximum of 20 hours at 580-640°C.

5. A method for manufacturing a steel plate having excellent PWHT resistance for a low-temperature pressure vessel, the method comprising:

reheating a steel slab at a temperature of 1050-1250°C, the steel slab including, in terms of wt%, 0.07-0.17% of C, 0.15-0.40% of Si, 0.3-0.7% of Mn, 0.012% or less of P, 0.015% or less of S, 3.0-4.0% of Ni, 0.03-0.25% of W, and a balance of Fe and inevitable impurities;
hot rolling the reheated steel slab and terminating the rolling at a temperature of 800°C or more to obtain a hot rolled steel plate;
heating the hot rolled steel plate to 800-950°C, followed by water cooling; and
tempering the water cooled steel material at 550-660°C for $\{1.5\times t + (10\text{-}30)\}$ minutes [wherein t is a thickness (mm) of the steel material].

6. The method of claim 5, further comprising:

a PWHT process for a maximum of 20 hours at 580-640°C after the tempering.

7. The method of claim 5, wherein a steel microstructure obtained by the tempering has 25-80 area% of tempered bainite and a balance of tempered martensite.

8. The method of claim 5, wherein a steel microstructure obtained by the tempering has 30-70 area% of tempered bainite and a balance of tempered martensite.

9. The method of claim 5, wherein a reduction rate per pass in the hot rolling is 5-30%.

10. The method of claim 5, wherein a cooling rate in the water cooling is 2.5 to 30°C/sec.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2016/012566

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/12(2006.01)i, C22C 38/08(2006.01)i, C22C 38/04(2006.01)i, C22C 38/02(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 38/12; C21D 6/00; C21D 8/02; C22C 38/00; C22C 38/02; C23F 11/00; B21B 3/00; C22C 38/08; C22C 38/04

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: weight, microstructure, tempered bainite, tempered martensite, PWHT, resistance, pressure vessel, steel plate

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	KR 10-0663219 B1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 03 January 2007 See paragraph [0111]; and claim 1.	1-10
A	KR 10-1388334 B1 (JFE STEEL CORPORATION) 22 April 2014 See paragraphs [0030]-[0069]; and figure 2.	1-10
A	KR 10-2015-0101734 A (HYUNDAI STEEL COMPANY) 04 September 2015 See paragraphs [0015], [0065]-[0086]; and figure 1.	1-10
A	JP 2013-533921 A (TATA STEEL NEDERLAND TECHNOLOGY BV.) 29 August 2013 See paragraphs [0006], [0040]; and figures 3-4.	1-10

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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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
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INTERNATIONAL SEARCH REPORT
Information on patent family members

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