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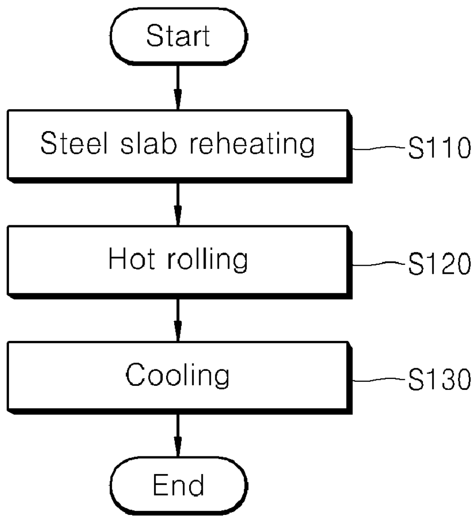
(54) STEEL PLATE FOR LINE PIPE, HAVING EXCELLENT HYDROGEN INDUCED CRACK RESISTANCE, AND PREPARATION METHOD THEREOF

(57) Disclosed are a steel plate for a line pipe having excellent hydrogen induced crack resistance with a tensile strength of 450 MPa or more, and a preparation method thereof. According to the present invention, the steel plate for a line pipe, having excellent hydrogen induced crack resistance comprises: 0.03~0.05 wt% of carbon (C); 0.2-0.3 wt% of silicon (Si); 0.5-1.3 wt% of manganese (Mn); 0.010 wt% or less of phosphorus (P); 0.005 wt% or less of sulfur (S); 0.02-0.05 wt% of aluminum (Al); 0.2-0.5 wt% of nickel (Ni); 0.2-0.3 wt% of chromium (Cr); 0.03-0.05 wt% of niobium (Nb); 0.02-0.05 wt% of vanadium (V); 0.01-0.02 wt% of titanium (Ti); 0.001-0.004 wt% of calcium (Ca); and a balance of iron (Fe) and inevitable impurities, and has a tensile strength of 450 MPa or more.

[Fig 1]



EP 2 623 625 A2

Description

[Technical Field]

[0001] The present invention relates to a technology of manufacturing a steel plate for pipelines having excellent hydrogen-induced crack resistance for use as materials for oil pipelines, and more particularly, to a steel plate for pipelines, which does not suffer from significant reduction in impact toughness and has excellent yield ratio and hydrogen-induced crack resistance, and a method for manufacturing the same.

[Background Art]

[0002] Recently, with recent trend of oil production from deep sea and cryogenic sites, oil pipelines are increasing in diameter and thus materials for oil pipelines require excellent mechanical and chemical properties.
[0003] To fulfill such requirement, there is an increasing need for development of a high strength/high toughness steel plate for pipelines that have excellent hydrogen-induced crack resistance. Such a steel plate for pipelines is generally produced through a rolling process.
[0004] Rolling generally includes slab reheating, hot rolling, cooling, and coiling.
[0005] In slab reheating operation, a half-steel product, that is, a steel slab is reheated.
[0006] In hot rolling operation, the reheated slab is subjected to hot rolling at a predetermined reduction rate using rolling rolls.
[0007] In cooling operation, the hot-rolled steel plate is cooled.
[0008] In coiling operation, the steel plate is coiled at a predetermined temperature.
[0009] For example, such a steel plate for pipelines is disclosed in Korean Patent Publication No. 10-2001-0060763A.

[Disclosure]

[Technical Problem]

[0010] An aspect of the present invention is to provide a steel plate for pipelines, which has a low yield ratio and a tensile strength of 450 MPa or more and exhibits excellent hydrogen-induced crack resistance to be applied to materials for oil pipelines and the like.
[0011] Another aspect of the present invention is to provide a method of manufacturing a steel plate for pipelines having excellent hydrogen-induced crack resistance by controlling process conditions while optimizing a composition ratio of chromium (Cr) and other alloy components excluding copper (Cu).

[Technical Solution]

[0012] In accordance with one embodiment of the present invention, a steel plate for pipelines having excellent hydrogen-induced crack resistance includes: carbon (C): 0.03 - 0.05 wt%, silicon (Si): 0.2 - 0.3 wt%, manganese (Mn): 0.5 - 1.3 wt%, phosphorous (P): 0.010 wt% or less, sulfur (S): 0.005 wt% or less, aluminum (Al): 0.02 - 0.05 wt%, nickel (Ni): 0.2 - 0.5 wt%, chromium (Cr): 0.2 - 0.3 wt%, niobium (Nb): 0.03 - 0.05 wt%, vanadium (V): 0.02 - 0.05 wt%, titanium (Ti): 0.01 - 0.02 wt%, calcium (Ca): 0.001 - 0.004 wt%, and the balance of iron (Fe) and other unavoidable impurities, and has a tensile strength of 450 MPa or more.
[0013] In accordance with another embodiment of the present invention, a method of manufacturing a steel plate for pipelines having excellent hydrogen-induced crack resistance includes: (A) reheating a steel slab, the steel slab including carbon (C): 0.03 - 0.05 wt%, silicon (Si): 0.2 - 0.3 wt%, manganese (Mn): 0.5 - 1.3 wt%, phosphorous (P): 0.010 wt% or less, sulfur (S): 0.005 wt% or less, aluminum (Al): 0.02 - 0.05 wt%, nickel (Ni): 0.2 - 0.5 wt%, chromium (Cr): 0.2 - 0.3 wt%, niobium (Nb): 0.03 - 0.05 wt%, vanadium (V): 0.02 - 0.05 wt%, titanium (Ti): 0.01 - 0.02 wt%, calcium (Ca): 0.001 - 0.004 wt% and the balance of iron (Fe) and other unavoidable impurities; (B) hot rolling the reheated steel slab; and (C) cooling the hot-rolled steel plate.

[Advantageous Effects]

[0014] The steel plate for pipelines according to one embodiment contains a suitable amount of chromium and is free from copper (Cu), which is generally used in manufacture of steel plates, thereby providing advantages such as insignificant reduction of impact toughness and excellent hydrogen-induced crack resistance.
[0015] The method of manufacturing a steel plate for pipelines according to another embodiment provides a steel plate which exhibits excellent hydrogen-induced crack resistance and allows insignificant reduction in impact toughness

even without containing copper (Cu) by controlling rolling and cooling conditions while optimizing a composition ratio of the steel plate.

[Description of Drawings]

[0016]

Fig. 1 is a schematic flowchart of a method of manufacturing a steel plate for pipelines in accordance with one embodiment of the present invention.
Fig. 2 is a graph depicting yield strength and tensile strength of specimens prepared in inventive examples and comparative examples.
Fig. 3 is a graph depicting impact resistance according to temperature of the specimens prepared in inventive examples and comparative examples.
Fig. 4 depicts pictures showing occurrence of cracking of specimens prepared in inventive examples and comparative examples upon HIC testing.

[Best Mode]

[0017] The above and other aspects, features, and advantages of the present invention will become apparent from the detailed description of the following embodiments in conjunction with the accompanying drawings. It should be understood that the present invention is not limited to the following embodiments and may be embodied in different ways, and that the embodiments are provided for complete disclosure and a thorough understanding of the present invention by those skilled in the art. The scope of the present invention is defined only by the claims. Like components will be denoted by like reference numerals throughout the specification.
[0018] Now, a steel plate for pipelines in accordance with one embodiment of the invention and a method for manufacturing the same will be described in more detail with reference to the accompanying drawings.

<u>**Steel plate for pipelines having excellent hydrogen-induced crack resistance**</u>

[0019] A steel plate for pipelines having excellent hydrogen-induced crack resistance according to one embodiment includes: carbon (C) : 0.03 - 0.05 wt%, silicon (Si): 0.2 - 0.3 wt%, manganese (Mn): 0.5 - 1.3 wt%, phosphorous (P): 0.010 wt% or less, sulfur (S): 0.005 wt% or less, aluminum (Al): 0.02 - 0.05 wt%, nickel (Ni): 0.2 - 0.5 wt%, chromium (Cr): 0.2 - 0.3 wt%, niobium (Nb): 0.03 - 0.05 wt%, vanadium (V): 0.02 - 0.05 wt%, titanium (Ti): 0.01 - 0.02 wt%, calcium (Ca): 0.001 - 0.004 wt%, and the balance of iron (Fe) and other unavoidable impurities.
[0020] Next, functions and amounts of the respective components of the steel plate for pipelines having excellent hydrogen-induced crack resistance according to the embodiment will be described in more detail.

<u>Carbon (C)</u>

[0021] Carbon (C) is an element for improving strength and hardness of steel.
[0022] A higher content of carbon can provide higher strength, but can cause deterioration in toughness of steel. In addition, processibility of the steel increase with increasing content of carbon, causing increase in tensile strength and yield point while decreasing elongation.
[0023] If the carbon content exceeds 0.05 wt% in the steel plate, the steel plate can be deteriorated in hydrogen-induced crack resistance. On the other hand, if the carbon content is less than 0.03 wt% in the steel plate, there can be difficulty in securing strength of the steel plate.
[0024] Thus, advantageously, carbon is present in an amount of 0.03 - 0.05 wt% in the steel plate according to the present invention.

<u>Silicon (Si)</u>

[0025] Silicon (Si) acts as an effective deoxidization element and reinforces ferrite structure in steel while improving yield strength.
[0026] Such effects of silicon can be sufficiently exhibited when the silicon content is 0.2 wt% or more. If the silicon content exceeds 0.3 wt% in the steel, toughness of the steel is deteriorated, reducing formability and causing difficulty in forging and processing.
[0027] Thus, advantageously, silicon is present in an amount of 0.2 - 0.3 wt% in the steel plate according to the present invention.

Manganese (Mn)

[0028] Manganese (Mn) serves to improve quenching properties and strength while increasing plasticity at high temperature to improve casting properties. In particular, manganese is likely to bind with an unfavorable component, that is, sulfur (S), thereby forming MnS inclusions.

[0029] If manganese is added in an excessive amount exceeding 1.3 wt%, a steel slab can suffer from central segregation, which promotes occurrence of hydrogen induced cracking at a segregated portion of the steel slab. If the manganese content is less than 0.5 wt%, it is difficult to secure strength of the steel.

[0030] Thus, advantageously, manganese is present in an amount of 0.5 - 1.3 wt% in the steel plate according to the present invention.

Phosphorous (P)

[0031] Phosphorous (P) is an element that is segregated into a grain boundary, reducing toughness and impact resistance of steel, and causes hydrogen-induced cracking in the steel.

[0032] Thus, advantageously, the phosphorous content is limited to 0.010 wt% or less in the steel plate according to the present invention.

Sulfur (S)

[0033] Sulfur (S) is an essential element coupled to manganese (Mn) to form MnS inclusions, thereby improving steel machinability. However, if sulfur is present in an excessive amount in the steel, sulfur deteriorates hot processibility of the steel, causes fracture, and forms coarse inclusions, causing defects upon surface treatment.

[0034] Thus, advantageously, sulfur is present in an amount of 0.005 wt% or less in the steel plate according to the present invention.

Aluminum (Al)

[0035] Aluminum (Al) is a strong deoxidization element and is coupled to nitrogen for grain refinement. However, if the aluminum content exceeds 0.05 wt% in the steel, there can be problems of deterioration in impact toughness and hydrogen-induced crack resistance. Further, if the aluminum content is less than 0.02 wt%, insufficient deoxidization can be obtained. Thus, advantageously, aluminum is present in an amount of 0.02~0.05 wt% in the steel plate according to the present invention.

Nickel (Ni)

[0036] In this invention, the content of nickel (Ni) is suitably adjusted to obtain desired yield strength and a yield ratio of 80% or less even in the absence of copper (Cu). If the nickel content is less than 0.2 wt%, it is difficult for the steel to have a yield strength of 450 MPa or more. If the nickel content exceeds 0.5 wt%, the steel has a yield ratio exceeding 80%. Thus, advantageously, nickel is present in an amount of 0.2 - 0.5 wt% in the steel plate according to the present invention.

Chromium (Cr)

[0037] According to the present invention, the steel plate includes chromium and is free from copper (Cu), which is generally used in manufacture of existing steel plates. Copper can cause deterioration of weldability and surface quality of the steel plate. Thus, the steel plate of the invention does not contain copper and contains an optimal amount of chromium.

[0038] Through addition of chromium, it is possible to manufacture a steel plate, which does not suffer from significant reduction in impact toughness and has a low yield ratio and excellent hydrogen-induced crack resistance. Here, if the chromium content exceeds 0.3 wt%, the steel plate can suffer from deterioration in hydrogen-induced crack resistance. If the chromium content is less than 0.2 wt%, the steel plate cannot obtain desired strength. Thus, advantageously, chromium is present in an amount of 0.2 - 0.3 wt% in the steel plate according to the present invention.

Niobium (Nb)

[0039] Niobium (Nb) prevents grains of steel from being coarsened at high temperature and promotes refinement of the grains to improve ductility and toughness of the steel.

[0040] To obtain strength improvement, niobium is desirably added in an amount of 0.03 wt% or more. Since secondary phases containing niobium can act as sites for initiation of hydrogen-induced cracking, an upper niobium limit is set to 0.05 wt%.

[0041] Thus, advantageously, niobium is present in an amount of 0.03~0.05 wt% in the steel plate according to the present invention.

Vanadium (V)

[0042] Vanadium (V) serves to improve resistance to hydrogen-induced cracking.

[0043] Advantageously, vanadium is present in an amount of 0.02 - 0.05 wt% in steel. If the vanadium content is less than 0.02 wt%, the effect of vanadium is not sufficiently exhibited. On the contrary, if the vanadium content exceeds 0.05 wt%, the steel can suffer from deterioration in toughness and hydrogen-induced crack resistance.

Titanium (Ti)

[0044] Titanium is an element which forms carbide or nitride in steel, and serves to improve both strength and low temperature toughness through grain refinement.

[0045] Titanium precipitates reduces a diffusion coefficient of hydrogen and increases hydrogen-induced crack resistance. If the titanium content exceeds 0.02 wt%, the steel can be deteriorated in hydrogen-induced crack resistance, and if the titanium content is less than 0.01 wit%, it is difficult to obtain desired strength. Thus, advantageously, titanium is present in an amount of 0.01~0.02 wt% in the steel plate according to the present invention.

Calcium (Ca)

[0046] Calcium is an element for spheroidizing MnS inclusions. MnS inclusions have a low melting point and are elongated upon rolling to act as starting point of hydrogen-induced cracking. The added calcium reacts with MnS to surround the MnS inclusions, thereby obstructing elongation of the MnS inclusions.

[0047] For efficient spheroidization of the MnS inclusions, calcium is advantageously present in an amount of 0.001 wt% or more. On the other hand, if the calcium content is excessive, an excess of oxide inclusions acting as starting points of hydrogen-induced cracking can be created. Thus, advantageously, an upper limit of the calcium content is set to 0.004 wt%.

[0048] Advantageously, the steel plate for pipelines according to the present invention has a yield ratio (YS)/(TS) of 80% or less.

[0049] In addition, advantageously, the microstructure of the steel plate comprises a composite structure consisting of acicular ferrite and bainite structures. Here, advantageously, a composite structure consisting of acicular ferrite and bainite structures occupies 30% or more of the entirety of the microstructure in terms of cross-sectional area ratio, and a composite structure consisting of ferrite and pearlite structures occupies 70% or less of the entirety of the microstructure in terms of cross-sectional area ratio.

[0050] If the composite structure consisting of acicular ferrite and bainite structures occupies 30% or less of the entirety of the microstructure in terms of cross-sectional area ratio, it is difficult to achieved desired strength.

Method of manufacturing a steel plate for pipelines having excellent hydrogen-induced crack resistance

[0051] Fig. 1 is a schematic flowchart of a method of manufacturing a steel plate for pipelines in accordance with one embodiment of the present invention.

[0052] Referring to Fig. 1, the method of manufacturing the steel plate for pipelines includes: (A) reheating a steel slab, the steel slab including carbon (C) : 0.03 ~ 0.05 wt%, silicon (Si): 0.2 - 0.3 wt%, manganese (Mn): 0.5 - 1.3 wt%, phosphorous (P): 0.010 wt% or less, sulfur (S): 0.005 wt% or less, aluminum (Al): 0.02 - 0.05 wt%, nickel (Ni): 0.2 - 0.5 wt%, chromium (Cr): 0.2 - 0.3 wt%, niobium (Nb): 0.03 - 0.05 wt%, vanadium (V): 0.050 ~ 0.095 wt%, titanium (Ti): 0.01 ~ 0.02 wt%, calcium (Ca): 0.001 - 0.004 wt%, and the balance of iron (Fe) and other unavoidable impurities; (B) hot rolling the reheated steel slab; and (C) cooling the hot-rolled steel plate.

[0053] The method of manufacturing the steel plate for pipelines according to the invention reduces fractions of polygonal ferrite and band structures relatively vulnerable to hydrogen-induced cracking, and includes finish-rolling to be performed at an Ar_3 transformation temperature or less to induce generation of mobile dislocations, which are advantageous for reduction of yield ratio. As the generation of mobile dislocations is induced by this method, the steel plate is reduced in yield strength, thereby lowering the yield ratio. That is, the steel plate according to the present invention has a low yield ratio, thereby providing excellent plastic deformation and anti-vibration effects. Further, in the manufacturing method of the steel plate according to the invention, the cooling rate is controlled to form acicular ferrite and bainite structures in a fraction of 30% or more.

[0054] The manufacturing method of the steel plate according to the present invention will be described in more detail.

(A) Slab reheating (S110)

[0055] In continuous casting of a steel slab, elements such as Mn, P, S, and the like are likely to be segregated in the steel slab, so that the steel slab has a higher concentration in a central region than in peripheral regions. Since such central segregation provides a propagation passage of hydrogen-induced cracking, it is desirable to suppress central segregation. During slab reheating, such elements causing central segregation diffuse into peripheral regions, thereby relieving central segregation.

[0056] Advantageously, reheating is performed at temperatures of 1000°C or more in order to relieve central segregation.

[0057] Further, Nb and V can be sufficiently dissolved in the steel during reheating of the steel slab and can be finely precipitated to increase strength of the steel during rolling. Thus, advantageously, the steel slab may be reheated at a temperature from 1100°C to 1250°C to achieve sufficient dissolution of Nb and V in the steel slab.

(B) Hot rolling (S120)

(Finish-rolling finishing temperature: 750~850°C)

[0058] As mentioned above, in the method of manufacturing the steel plate according to the invention, finish-rolling is performed at an Ar_3 transformation temperature or less to induce generation of mobile dislocations which are favorable to reduction of the yield ratio.

[0059] The finish-rolling finishing temperature may be set to 750°C or more to ensure that the steel plate has excellent hydrogen-induced crack resistance and the acicular ferrite and bainite structures are formed in a fraction of 30% or more.

[0060] Although the pearlite fraction is decreased with increasing finish-rolling finishing temperature before initiation of quenching, the strength of the steel is also decreased. Thus, advantageously, the finish-rolling finishing temperature is set to 850°C or less to prevent the decrease in strength of the steel plate.

(Finish-rolllng reduction rate: 50% to 70% based on a reduction rate of 100 at an Ar_3 transformation temperature or less)

[0061] Advantageously, the reduction rate of hot rolling is set in the range of 50% to 70% based on a reduction rate of 100 at an Ar_3 transformation temperature or less in order to restrict an average grain size of acicular ferrite microstructure in a final product of the steel plate according to the present invention.

(C) Cooling (S130)

(Cooling finishing temperature: 300~450°C)

[0062] In order to improve hydrogen-induced crack resistance, the cooling finishing temperature may be restricted in the cooling stage.

[0063] An excess of ferrite and pearlite microstructures can cause deterioration not only in hydrogen-induced crack resistance but also in low temperature toughness. Thus, the cooling finishing temperature may be set to 300°C.

[0064] However, since a cooling finishing temperature exceeding 450°C can cause increase in pearlite fraction in the microstructure of the steel plate, the cooling finishing temperature may be sent to 450°C or less.

(Cooling rate: 15~25°C/sec)

[0065] By controlling the cooling rate in the cooling stage, it is possible to control central microstructure and hardness of the steel plate according to the invention.

[0066] A cooling rate of less than 15°C/sec makes it difficult for the steel plate to obtain sufficient hardness. In addition, a cooling rate exceeding 25°C/sec can cause deterioration in hydrogen-induced crack resistance.

[0067] Advantageously, the cooling rate is set in the range of 15~25°C/sec.

<u>Example</u>

[0068] Next, constitution and operation of the present invention will be described in more detail with reference to some inventive examples. It should be noted that the following examples are provided for illustration only and should not be construed in any way as limiting the scope of the present invention.

[0069] Descriptions of details apparent to those skilled in the art will be omitted.

1. Preparation of specimens

[0070] Table 1 shows compositions of steel specimens prepared in examples and comparative examples.

[0071] In Table 1, steel specimens prepared in Comparative Examples 1 to 3 are conventional steel plates for pipelines, and steel specimens prepared in Examples 1 to 3 are inventive steel plates for pipelines in which chromium and other alloy components are present in a suitable composition ratio without adding copper.

Table 1

No.	C	Si	Mn	P	S	Cr	Ni	Al	Cu	Ti	Nb	V	Ca	Ca/S	Ceq
CE 1	0.04	0.25	1.20	0.005	0.0012	-	-	0.021	-	0.013	0.04	0.027	0.0018	1.4	0.245
CE 2	0.04	0.25	1.20	0.005	0.0012	-	0.23	0.020	0.16	0.014	0.039	0.031	0.0019	1.6	0.272
CE 3	0.04	0.25	1.21	0.005	0.0011	0.24	0.24	0.022	0.20	0.013	0.038	0.028	0.0017	1.5	0.325
Ex. 1	0.04	0.25	1.20	0.005	0.0012	0.23	0.21	0.021	-	0.014	0.040	0.029	0.0019	1.6	0.302
Ex. 2	0.04	0.24	1.21	0.006	0.0011	0.24	0.40	0.021	-	0.014	0.040	0.030	0.0018	1.6	0.332
Ex. 3	0.04	0.26	1.20	0.006	0.0012	0.25	0.23	0.020	-	0.014	0.039	0.027	0.0018	1.5	0.311

[0072] The steel specimens prepared in Comparative Examples 1 to 3 are conventional steel plates for pipelines, and the steel specimens prepared in Examples 1 to 3 are inventive steel plates for pipelines in which chromium and other alloy components are present in a suitable composition ratio without adding copper.

2. Measurement and evaluation of physical properties

[0073] Each of the specimens prepared in the comparative examples and the inventive examples was subjected to tensile testing, impact testing and HIC (hydrogen-induced cracking) testing to observe occurrence of cracking.
[0074] Fig. 2 is a graph depicting yield strength and tensile strength of each of the specimens prepared in the inventive examples and the comparative examples. In the bar graph, left-side bars indicate yield strength (YS) and right-side bars indicate tensile strength (TS).
[0075] The specimens of Examples 1 to 3 did not contain copper (Cu), which is included in conventional steel plates for pipelines. It can be confirmed that these steel specimens have a tensile strength of 450 MPa or more even without containing Cu.
[0076] Since the specimens of the inventive examples did not undergo significant reduction in impact toughness even without containing Cu, the specimens of the inventive examples had similar results to the specimens of the comparative examples in impact testing. Fig. 3 is a graph depicting results of impact testing with respect to the respective specimens of the inventive examples and the comparative examples.
[0077] Results of tensile testing and impact testing are summarized in Table 2.

Table 2

Specimen	Tensile testing			Impact testing	
	YS (MPa)	TS (MPa)	EL (%)	0°C	-80°C
Comparative Example 1	452	531	35	357	302
Comparative Example2	484	560	30	375	302
Comparative Example3	512	610	25	324	305
Example 1	455	580	27	337	304
Example2	533	651	29	362	327
Example3	480	640	27	359	292

[0078] Fig. 4 shows results of hydrogen-induced cracking testing.
[0079] Pictures of the specimens before and after HIC testing are provided in this drawing.
[0080] It can be seen that the specimens of Examples 1 to 3 undergo no cracking and have excellent hydrogen-induced crack resistance.
[0081] In Table 3, results of HIC testing with respect to the respective specimens are summarized.

Table 3

Specimen	Total length of crack (mm)	Total thickness of crack (mm)	CLR	CTR	CSR
Comparative Example1	3.4	0.07	5.7 %	0.23 %	0.04 %
Comparative Example2	1.8	0.2	3 %	0.67 %	0.06 %
Comparative Example3	0	0	0	0	0
Example1, 2, 3	0	0	0	0	0
CLR: Crack length ratio, CTR: Crack thickness ratio, CSR: Crack sensitivity ratio					

[0082] Although some embodiments have been described herein, it will be understood by those skilled in the art that these embodiments are provided for illustration only, and various modifications, changes, alterations and equivalent embodiments can be made without departing from the scope of the present invention. Therefore, the scope and sprit of the present invention should be defined only by the accompanying claims and equivalents thereof.

Claims

1. A steel plate comprising:

   carbon (C), 0.03 ~ 0.05 wt%; silicon (Si), 0.2 - 0.3 wt%; manganese (Mn), 0.5 - 1.3 wt%; phosphorous (P), 0.010 wt% or less; sulfur (S), 0.005 wt% or less; aluminum (Al), 0.02 - 0.05 wt%; nickel (Ni), 0.2 - 0.5 wt%; chromium (Cr), 0.2 ~ 0.3 wt%; niobium (Nb), 0.03 - 0.05 wt%; vanadium (V), 0.02 - 0.05 wt%; titanium (Ti), 0.01 - 0.02 wt%; calcium (Ca), 0.001 - 0.004 wt%; and the balance of iron (Fe) and other unavoidable impurities,
   the steel plate having a tensile strength of 450 MPa or more.

2. The steel plate according to claim 1, wherein the steel plate has a yield ratio (yield strength/tensile strength) of 80% or less.

3. The steel plate according to claim 1, wherein microstructure of the steel plate is a composite structure including acicular ferrite and bainite structures.

4. The steel plate according to claim 3, wherein the composite structure including acicular ferrite and bainite structures occupies 30% or more of the entirety of the microstructure in terms of cross-sectional area ratio.

5. The steel plate according to claim 4, wherein a composite structure including ferrite and pearlite structures occupies 70% or less of the entirety of the microstructure in terms of cross-sectional area ratio.

6. A method of manufacturing a steel plate, comprising:

   (A) reheating a steel slab including: carbon (C), 0.03 - 0.05 wt%; silicon (Si), 0.2 - 0.3 wt%; manganese (Mn), 0.5 - 1.3 wt%; phosphorous (P), 0.010 wt% or less; sulfur (S), 0.005 wt% or less; aluminum (Al), 0.02 - 0.05 wt%; nickel (Ni), 0.2 - 0.5 wt%; chromium (Cr), 0.2 - 0.3 wt%; niobium (Nb), 0.03 - 0.05 wt%; vanadium (V), 0.02 - 0.05 wt%; titanium (Ti), 0.01 ~ 0.02 wt%; calcium (Ca), 0.001- 0.004 wt%; and the balance of iron (Fe) and other unavoidable impurities;
   (B) hot rolling the reheated steel slab; and
   (C) cooling the hot-rolled steel plate.

7. The method according to claim 6, wherein the reheating (A) is performed at a temperature of 1100 ~ 1250°C.

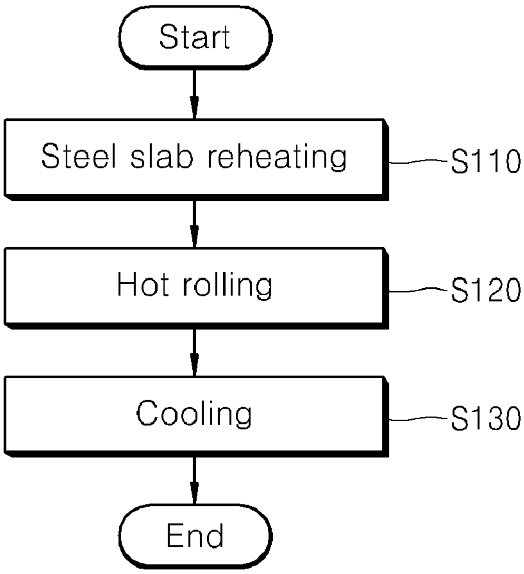
8. The method according to claim 6, wherein the hot rolling (B) is performed at a reduction rate of 50% to 70% based on the whole reduction rate of 100 at an Ar_3 temperature or less.

9. The method according to claim 6, wherein the hot rolling (B) has a rolling finishing temperature of 750~850°C.

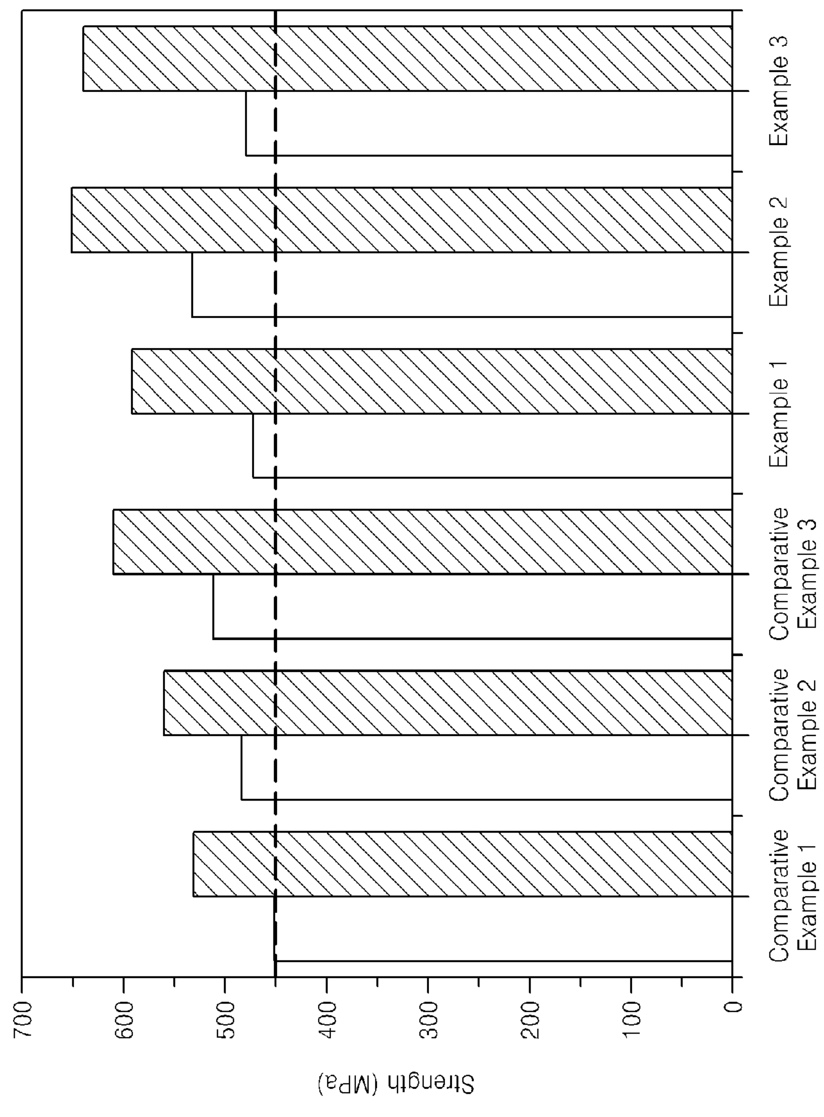
10. The method according to claim 6, wherein the cooling (C) has a cooling finishing temperature of 300~450°C.

11. The method according to claim 6, wherein the cooling (C) is performed at a cooling rate of 15~25 °C /sec.

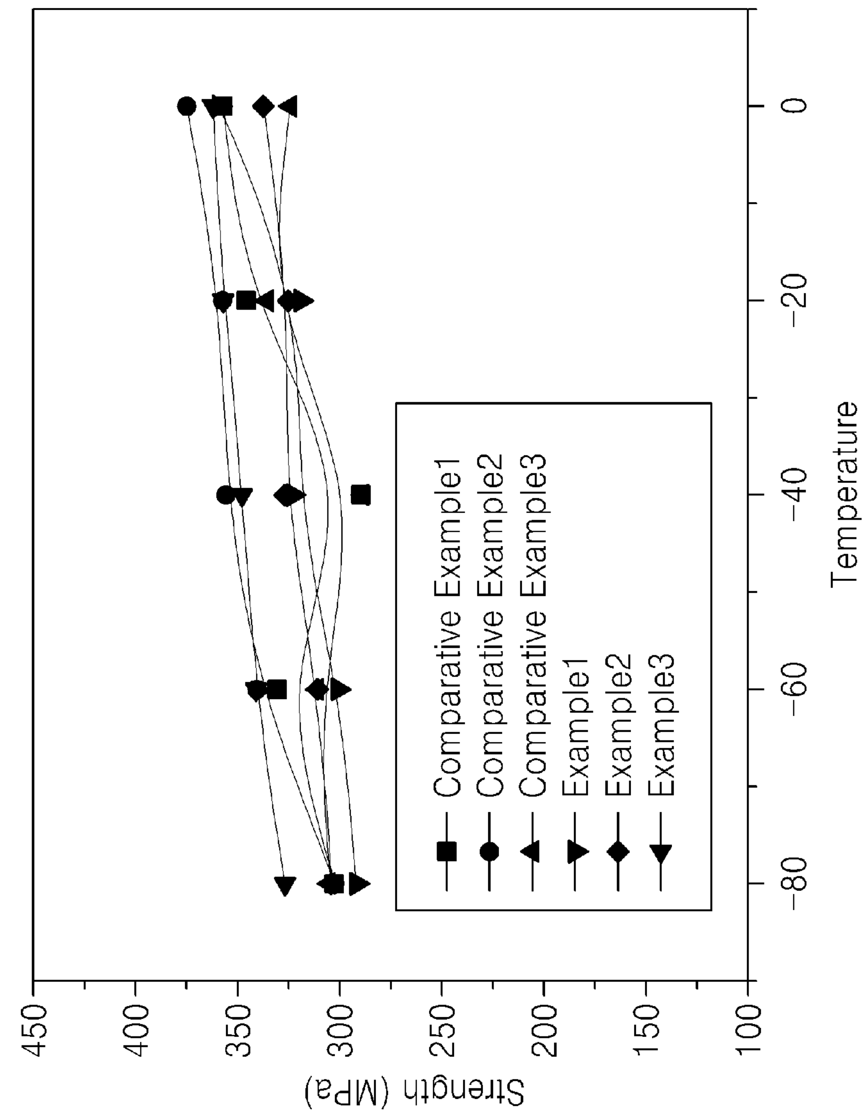
[Fig 1]


Start
Steel slab reheating
S110
Hot rolling
S120
Cooling
S130
End

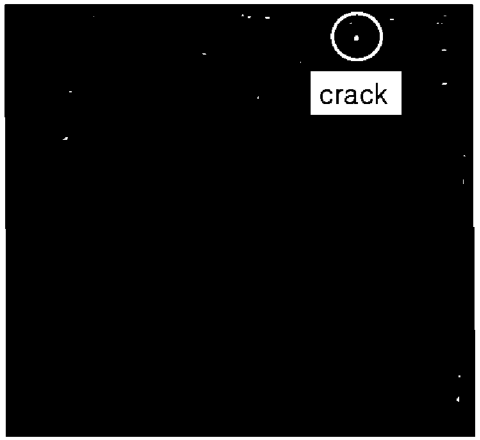
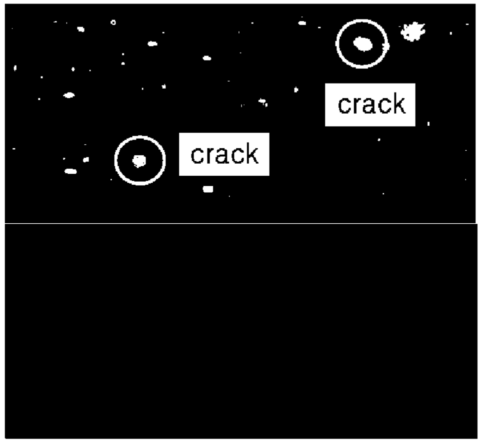
[Fig 2]


Strength (MPa)
0
100
200
300
400
500
600
700
Comparative Example 1
Comparative Example 2
Comparative Example 3
Example 1
Example 2
Example 3

[Fig 3]


Strength (MPa)
450
400
350
300
250
200
150
100
Temperature
-80
-60
-40
-20
0
Comparative Example1
Comparative Example2
Comparative Example3
Example1
Example2
Example3

[Fig 4]

BEFORE HIC TEST	AFTER HIC TEST	TEST No.	Ca/S
		Comparative Example1	1.4
		Comparative Example2	1.6
		Comparative Example3	1.5
		Example 1 ~ 3	1.5~1.6

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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