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(54) HIGH-STRENGTH STEEL SHEET HAVING EXCELLENT DUCTILITY AND LOW-TEMPERATURE TOUGHNESS AND METHOD FOR MANUFACTURING THEREOF

HOCHFESTES STAHLBLECH MIT HERVORRAGENDER DUKTILITÄT UND TIEFTEMPERATURBESTÄNDIGKEIT SOWIE VERFAHREN ZUR HERSTELLUNG DAVON

TÔLE À HAUTE RÉSISTANCE AYANT UNE EXCELLENTE DUCTILITÉ ET UNE EXCELLENTE TÉNACITÉ À BASSE TEMPÉRATURE ET SON PROCÉDÉ DE FABRICATION

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Description

[Technical Field]

[0001] The present invention relates to a structural steel sheet suitable for ships or steel structures and, more particularly, to a high-strength steel sheet having excellent ductility and low-temperature toughness and a method for manufacturing the same.

[Background Art]

[0002] A ship, a steel structure, or the like may experience accidents such as flooding or sinking as a steel plate is fractured by external impacts such as a collision.. In addition, cracks may occur due to forming processes during the manufacture of the ship or steel structure. In this case, there may be a problem such as the increase in a construction period or manufacturing costs.
[0003] In order to solve the above problems, it is necessary to increase an elongation while maintaining the strength of the steel sheet used in ships or steel structures at the required level. The higher the elongation of the steel, the more deformation may be accommodated until the steel is fractured even if the steel is deformed due to the external impacts, etc., so that the occurrence of fracture may be suppressed and the possibility of the occurrence of cracks due to processing may be reduced.
[0004] In general, since the strength and elongation of steel have an inverse relationship, it is very hard to increase the elongation while maintaining the strength. Nevertheless, the following technologies have been developed.
[0005] For example, Patent Document 1 discloses a steel plate having excellent collision absorption property while having a tensile strength of 490 MPa or more and a uniform elongation of 15% or more by controlling an average grain diameter of ferrite as a main phase between 3 and 12 μm and making the ferrite fraction 90 % or more while refining an average equivalent circle diameter of a second phase to 0.8 μm or less.
[0006] Patent Document 2 discloses a steel sheet having a microstructure made of ferrite and a hard second phase, a volume fraction of the ferrite of 75% or more over the entire sheet thickness, a hardness of Hv 140 or more and 160 or less, and an average crystal grain size of 2 μm or more by applying a process including front ooling, air cooling, and rear ooling after rolling.
[0007] In addition, Patent Document 3 discloses a thick steel plate in which a microstructure is mainly composed of ferrite and pearlite in order to increase energy absorption capability during a collision, and an average dislocation density of the ferrite is lowered to a certain level or less while a hardness, a fraction, an average area, and an average circumferential length of the phase satisfying certain conditions. Further, in order to obtain the above-described thick steel plate, a process of heating a steel material to the temperature higher than a normal reheating temperature, and then performing controlled rolling on the steel material and air cooling or weak water cooling on the rolled steel material is disclosed. EP 2 752 499 A1 and EP 2 940 172 A1 disclose steel sheet with low temperature toughness.
[0008] However, it may be found that the above-described techniques have several problems.
[0009] Specifically, although the fracture of the steel plate is more related to total elongation (or fracture elongation) than uniform elongation, Patent Document 1 discloses only uniform elongation, and but does not substantially disclose the effect of suppressing defects such as the fracture due to external impacts or the like. Patent Document 2 also discloses only the uniform elongation, and therefore, the total elongation or the like of the steel plate disclosed in Patent Document 2 is unclear. On the other hand, Patent Document 3 discloses the total elongation, but does not disclose securing the toughness at all, which is a very important property of the structural steel sheet.
[0010] In other words, it is important to secure not only strength and ductility (total elongation), but also toughness, in particular, low-temperature toughness, as properties required for the structural steel sheet suitable for use in ships, steel structures, or the like. Accordingly, it is necessary to develop a structural steel sheet having all of these properties.
[0011]

(Patent Document 1) Korean Patent Laid-open Publication No. 10-2006-0127762
(Patent Document 2) Korean Patent Laid-open Publication No. 10-2016-0104077
(Patent Document 3) Japanese Patent No. 5994819

[Disclosure]

[Technical Problem]

[0012] An aspect of the present invention is to provide a high-strength steel sheet having excellent ductility and low-temperature toughness and a method for manufacturing the same in providing a steel sheet suitable for a structural use .

[0013] The object of the present invention is not limited to the abovementioned contents . Those skilled in the art will have no difficulty in understanding an additional object of the present invention from the general contents of the present specification within the scope of the appended claims.

[Technical Solution]

[0014] The invention is defined in the appended claims.

[Advantageous Effects]

[0015] As set forth above, it is possible to provide a steel sheet having excellent low-temperature toughness as well as high strength and high ductility.
[0016] In addition, the steel sheet of the present invention has an effect that may be advantageously applied as a structural steel sheet.

[Best Mode for Invention]

[0017] In general, as the strength of steel increases, the ductility of the steel is relatively reduced. Accordingly, it is not easy to manufacture steel having high strength and excellent elongation. In addition, the high elongation of steel does not necessarily mean that the steel has excellent low-temperature toughness, so it is more difficult to secure excellent low-temperature toughness as well as high strength and high ductility.
[0018] However, as the present inventors have deeply researched the development of a steel sheet capable of securing the low-temperature toughness as well as the high strength and high ductility, the present inventors found that it is possible to provide a steel sheet having target mechanical properties by defining alloy compositions and manufacturing conditions as follows, and reached the completion of the present disclosure.
[0019] Hereinafter, the present invention will be described in detail.
[0020] Hereinafter, the reason for limiting the alloy compositions of the steel sheet provided by the present invention as described above will be described in detail.
[0021] On the other hand, unless specifically stated in the present invention, the content of each element is based on a weight, and the fraction of a microstructure is based on an area.

Carbon (C) : 0.05 to 0.12%

[0022] Carbon (C) is an element that affects the fraction of pearlite in a steel microstructure, and is advantageous in securing strength. In order to secure a target level of strength in the present disclosure, the carbon (C) may be contained in an amount of 0.05% or more. In particular, in a series of processes (rolling and cooling processes) for manufacturing the steel sheet of the present disclosure, C is added in an amount of 0.05% or more. However, when the content exceeds 0.12%, the fraction of the pearlite in the steel microstructure becomes excessive, so low-temperature toughness decreases.
[0023] Therefore, in the present invention, C is contained in an amount of 0.05 to 0.12%, and advantageously, may be contained in an amount of 0.06 to 0.10%.

Silicon (Si): 0.2 to 0.5%

[0024] Silicon (Si) is an element that helps deoxidation of steel, increases hardenability, and iscontained in an amount of 0.2% or more in order to secure a target level of strength. However, when the content exceeds 0.5%, there is a problem that the strength is excessively increased, thereby impairing total elongation and low-temperature impact toughness.
[0025] Therefore, in the present invention, Si is contained in an amount of 0.2 to 0.5%.

Manganese (Mn): 1.2 to 1.8%

[0026] Manganese (Mn) is an element that is useful for increasing the strength without significantly reducing the elongation of the steel. In order to secure the target level of strength in the present disclosure, Mn is contained in an amount of 1.2% or more, but when the content exceeds 1.8%, the strength of the steel increases significantly, thereby making it difficult to secure ductility.
[0027] Therefore, in the present invention, Mn is contained in an amount of 1.2 to 1.8%, and advantageously, may be contained in an amount of 1.4 to 1.7%.

Phosphorus (P): 0.012% or less

[0028] Phosphorus (P) is an impurity that is inevitably mixed in steel, and needs to be minimized because the phosphorus (P) reduces the ductility and low-temperature impact toughness of the steel. In the present disclosure, even if P is contained in an amount of 0.012% or less, since there is no great difficulty in securing the intended physical properties, an upper limit of P is limited to 0.012%. However, 0% may be excluded in consideration of a load during a process of manufacturing steel.

Sulfur (S): 0.005% or less

[0029] Sulfur (S) is an impurity that is inevitably mixed in steel, such as P, and is necessary to minimize its content since the sulfur (S) forms sulfides and significantly reduces ductility. In the present disclosure, even if S is contained in an amount of 0.005% or less, since there is no great difficulty in securing the intended physical properties, an upper limit of S may be limited to 0.005%. However, 0% may be excluded in consideration of a load during the process of manufacturing steel.

Aluminum (Al): 0.01 to 0.06%

[0030] Aluminum (Al) is an essential element for deoxidation of steel, and is contained in an amount of 0.01% or more in order to secure cleanliness of the steel. However, when the content is excessive, since the toughness of a welded joint may be impaired, the content is limited to 0.06% or less in consideration of the impairment of the toughness.

Titanium (Ti): 0.005 to 0.02%

[0031] Titanium (Ti) is an element useful for refining grains of ferrite during austenite-ferrite transformation by suppressing excessive growth of austenite during a heating process in the process of manufacturing steel. In order to sufficiently obtain the above-described effects, Ti is contained in an amount of 0.005% or more, but when the content exceeds 0.02%, coarse nitrides are formed, thereby reducing the effect of grain refinement and deteriorating impact toughness.

[0032] Therefore, in the present invention, Ti is contained in an amount of 0.005 to 0.02%.

Niobium (Nb): 0.01 to 0.03%

[0033] Niobium (Nb) is effective in refining grains of austenite by being precipitated as carbonitride during a rolling process in the process of manufacturing steel, and contributes to the improvement in the strength. In order to sufficiently obtain such an effect, Nb is added in an amount of 0.01% or more, but when the content exceeds 0.03%, the strength excessively increases, thereby making it difficult to secure the ductility and impairing the toughness of a welded joint.

[0034] Therefore, in the present invention, Nb is contained in an amount of 0.01 to 0.03%.

Nitrogen (N): 0.002 to 0.006%

[0035] Nitrogen (N) is advantageous in obtaining an effect of suppressing the growth of the grains of the austenite during the heating of the steel by being combined with the Ti, Nb, or the like and refining grains by forming fine carbonitrides during the rolling. To this end, N is added in an amount of 0.002% or more, but when the content exceeds 0.006%, the surface quality of steel cast and sheet may be deteriorated.

[0036] Therefore, in the present invention, N is contained in an amount of 0.002 to 0.006%.

Nickel (Ni): 0.5% or less (including 0%)

[0037] Nickel (Ni) is an element that does not significantly impair the elongation while improving strength by refining grains of ferrite, similar to the Mn. By adding such Ni in a certain amount, the strength, ductility, and low-temperature toughness targeted in the present disclosure may be more advantageously secured. However, when the content exceeds 0.5%, the elongation decreases and the manufacturing cost increases, so Ni is contained in an amount of 0.5% or less.

[0038] In the present invention, even if Ni is not added, it is not unreasonable to secure physical properties, and Ni may be 0%.

[0039] The remaining component of the present invention is iron (Fe). However, in a general manufacturing process, unintended impurities may inevitably be mixed from a raw material or the surrounding environment, and thus, these impurities may not be excluded. Since these impurities are known to anyone with ordinary skill in the manufacturing process, all the contents are not specifically mentioned in the present specification.

[0040] Accordingly, the present invention forms a ferrite-pearlite microstructure of the steel sheet in order to secure a balance between the strength and ductility of the steel sheet, and secure the intended physical properties by minimizing the fraction of the bainite which may be partially contained during the process of manufacturing a steel sheet.

[0041] In the second phase, the pearlite is contained in an area fraction of 5 to 25%, and the bainite is contained in an area fraction of 2% or less (including 0%) . Specifically, when the fraction of the pearlite is less than 5%, it is difficult to secure the target level of strength, and when the fraction exceeds 25%, the elongation decreases and the target level of toughness may not be achieved. On the other hand, when the fraction of the bainite exceeds 2%, the post elongation is lowered, and thus it is difficult to secure the target level of total elongation in the present disclosure.

[0042] On the other hand, the smaller the average grain size (equivalent circle diameter) of the polygonal ferrite, the more advantageous it is to improve the strength and low-temperature toughness of the steel, while the elongation decreases, so it is necessary to properly control the average grain size of the polygonal ferrite.

[0043] The relationship between the average grain size and elongation of the polygonal ferrite is not linear, and when the average grain size of the polygonal ferrite is smaller than 2 μm, the elongation tends to decrease rapidly.

[0044] In the present invention by controlling the average grain size of the polygonal ferrite to 2 to 8 μm, it is possible to secure the balance between the strength and ductility from appropriate refinement. When the average grain size of the polygonal ferrite is less than 2 μm, the uniform elongation is significantly reduced, thereby making it difficult to secure the total elongation. On the other hand, when the size exceeds 8 μm, the fraction of the pearlite should be increased to secure the target level of strength, but the low-temperature impact toughness is deteriorated.

[0045] More specifically, the steel sheet of the present invention having a microstructure as described above has a yield strength of 355 MPa or more, a tensile strength of 490 MPa or more, an elongation of 30% or more, and an impact toughness of 100 J or more at -40°C, and therefore, may secure the low-temperature toughness as well as the strength and ductility.

[0046] The steel sheet of the present invention has a thickness of 8 to 15mm.

[0047] Hereinafter, a method for manufacturing high-strength steel sheet having excellent ductility and low-temperature toughness according to another aspect of the present invention will be described in detail.

[0048] The high-strength steel sheet according to the present invention is manufactured through a series of processes of [heating-hot rolling-cooling] a steel slab that satisfies the alloy compositions proposed in the present invention.

[0049] Hereinafter, each of the above process conditions will be described in detail.

Heating Steel Slab

[0050] In the present invention, the steel slab is subjected to the heating to homogenizing followed by the hot rolling. In this case, the heating process is preferably performed at 1100 to 1200°C.

[0051] When the heating temperature is less than 1100°C, the steel slab is not sufficiently uniform, and Nb carbonitride or the like present in the center of the thickness of the steel slab is not sufficiently dissolved, thereby making it difficult to secure the target level of strength. On the other hand, when the temperature exceeds 1200°C, the elongation and low-temperature toughness are degraded due to the abnormal grain growth of the grains of the austenite, which is not preferable.

[0052] In performing the heating in the above-described temperature range, the heating time may be set differently according to the thickness of the steel slab, and it is preferable to set it so that the steel slab may be sufficiently uniform from the surface to the center of the thickness of the steel slab. Usually, heating may be performed for 1 minute or more per 1 mm of the thickness of the steel slab.

Hot Rolling

[0053] The hot-rolled steel plate is manufactured by hot rolling the heated steel slab according to the above. In this case, the two-step rolling may be performed.

[0054] Specifically, the rough rolling is performed in the first rolling, which may be performed immediately after the extraction of the heated steel slab from the heating furnace. The rough rolling may include broadside rolling to secure the width of the final steel plate, and the rolling may be carried out up to the thickness at which the finish rolling, which is the subsequent second rolling, begins.

[0055] As mentioned above, the finish rolling is performed as the second rolling, and the rolling is performed so as to have an intended thickness. In the present invention, the finish rolling is performed in a temperature range of Ar3 + 70°C to Ar3 + 170°C.

[0056] In general, the lower the temperature during the finish rolling, the smaller the grain size of the ferrite in the final microstructure, so that the strength and low-temperature toughness may be improved and the elongation may be reduced.

[0057] Therefore, in order to simultaneously improve the ductility as well as the strength and low-temperature toughness targeted in the present invention, the finish rolling needs to be performed in an appropriate temperature range. But the temperature range may be very narrow, in this case, there is a problem that it is difficult to industrially manufacture the steel sheet.

[0058] Accordingly, as the present inventors have deeply studied the relationship between the alloy compositions and the manufacturing process, the present inventors found that it is possible to expand the temperature range advantageous for securing the intended physical properties during the finish rolling by appropriately adding Mn or Mn and Ni in the alloy compositions.

[0059] Specifically, the Mn and Ni lower the ferrite transformation temperature to induce the ferrite grain refinement, thereby improving the strength and low-temperature toughness and not significantly impairing the elongation.

[0060] As a result, by performing the finish rolling the steel with the content of Mn and Ni proposed in the present invention in a temperature range of Ar3 + 70°C to Ar3 + 170°C, the steel sheet having excellent strength and ductility as well as low-temperature toughness may be obtained.

[0061] When the temperature during the finish rolling is less than Ar3 + 70°C, the strength of the steel increases rapidly and the elongation decreases significantly. On the other hand, when the temperature exceeds Ar3 + 170°C, the austenite becomes coarse and the grains of the ferrite in the final microstructure, become coarse, so there is a problem that the strength and low-temperature toughness are lowered.

[0062] Here, Ar3 may be represented by the following formula.

[Ar3 = 910 - 310C - 80Mn - 20Cu - 55Ni - 15Cr - 80Mo (each element is represented by weight percent)]

[0063] In addition, it is preferable to perform the finish rolling such that the cumulative reduction ratio is 60 to 90% during the finish rolling in the above-described temperature range. When the cumulative reduction ratio during the finish rolling is less than 60%, the average grain size of the ferrite becomes coarse, and thus, it is difficult to secure the strength of the target level, whereas when the cumulative reduction ratio exceeds 90%, the average grain size of the ferrite becomes too fine, and thus, it is advantageous for securing strength but the elongation is deteriorated.

Cooling

[0064] As described above, the hot-rolled steel plate manufactured by performing the hot rolling is cooled. In this case, cooling is performed to room temperature through air cooling, which means cooling in the atmosphere.

[0065] When water cooling is applied during the above cooling, the ferrite is excessively refined or the fraction of a hard phase such as the bainite as the second phase increases, and thus, the probability of cooling unevenness increases and it is difficult to secure the post elongation, so there is a problem that it becomes difficult to secure the total elongation.

[0066] The steel sheet of the present invention manufactured through the series of manufacturing processes described above has a thickness of 8 to 15 mm, and the microstructure intended in the present invention may be uniformly formed, regardless of any thickness within the thickness range.

[0067] Hereinafter, the present invention will be described in more detail through embodiments. It should be noted that the following examples are for describing exemplary examples of the present invention, and the scope of the present invention is determined by matters described in the claims and matters reasonably inferred therefrom.

[Mode for Invention]

(Inventive Example)

[0068] After preparing molten steel having the alloy compositions shown in Table 1, the steel slab having a thickness of 250 mm was obtained by a continuous casting method. Thereafter, a steel plate having a thickness of 8 to 15 mm was manufactured through heating, rolling, and cooling under the conditions shown in Table 2 below. When it comes to cooling, air and water cooling were applied, and in the case of the water cooling, the cooling was performed at a cooling rate of about 20°C/s, the water cooling was terminated at 650°C, and then the air cooling was performed to room temperature.

[Table 1]

Steel	Alloy Composition (wt%)						Ar3				
No.	C	Si	Mn	P	S	Al	Ti	Nb	N	Ni	
1	0.11	0.23	1.34	0.008	0.003	0.035	0.014	0.022	0.003	0	769
2	0.09	0.28	1.47	0.011	0.002	0.023	0.012	0.026	0.004	0	765
3	0.08	0.34	1.53	0.007	0.004	0.019	0.013	0.021	0.003	0.13	756
4	0.08	0.25	1.34	0.007	0.003	0.041	0.016	0.014	0.005	0.45	753
5	0.07	0.42	1.63	0.009	0.004	0.031	0.008	0.026	0.003	0	758
6	0.05	0.39	1.74	0.008	0.002	0.033	0.009	0.026	0.003	0	755
7	0.14	0.25	1.35	0.007	0.003	0.038	0.012	0.021	0.004	0	759
8	0.04	0.36	1.65	0.009	0.003	0.025	0.013	0.027	0.003	0	766
9	0.08	0.41	1.58	0.009	0.004	0.048	0.002	0.018	0.005	0	759
10	0.09	0.29	1.45	0.011	0.003	0.036	0.012	0.003	0.004	0	766

[Table 2]

Steel No.	Thickne ss (mm)	Heating Temperature (°C)	Finish Rolling Temperature (°C)	Finish Rolling Cumulative Reduction Ratio (%)	Cooling	Division
1	15	1124	893	70	Air Cooling	Inventive Example 1
2	15	1135	903	80	Air Cooling	Inventive Example 2
3	15	1108	881	80	Air Cooling	Inventive Example 3
4	15	1123	854	85	Air Cooling	Inventive Example 4
5	15	1143	884	80	Air Cooling	Inventive Example 5
6	15	1155	843	75	Air Cooling	Inventive Example 6
2	11	1172	881	80	Air Cooling	Inventive Example 7
3	11	1149	865	80	Air Cooling	Inventive Example 8
4	11	1155	853	70	Air Cooling	Inventive Example 9
5	8	1189	892	70	Air Cooling	Inventive Example 10
6	8	1194	913	80	Air Cooling	Inventive Example 11
7	15	1243	909	80	Air Cooling	Comparative Example 1
8	15	1133	892	75	Air Cooling	Comparative Example 2

(continued)

Steel No.	Thickne ss (mm)	Heating Temperature (°C)	Finish Rolling Temperature (°C)	Finish Rolling Cumulative Reduction Ratio (%)	Cooling	Division
9	15	1119	845	85	Water Cooling	Comparative Example 3
10	15	1129	841	50	Water Cooling	Comparative Example 4
5	15	1134	852	80	Water Cooling	Comparative Example 5
3	15	1116	804	80	Air Cooling	Comparative Example 6
1	15	1125	979	70	Air Cooling	Comparative Example 7
6	23	1132	867	85	Air Cooling	Comparative Example 8

[0069] In order to observe the microstructure of each steel plate manufactured as described above, after a specimen was cut at the quarter of of the thickness of each steel plate, polished and etched with a nital etching solution, the specimen was observed with an optical microscope. Thereafter, the average grain size (equivalent circle diameter) of polygonal ferrite, the fraction of pearlite, and the fraction of bainite were measured using an image analyzer connected to an optical microscope, and the results are shown in Table 3 below. In this case, the fractions of the pearlite and bainite were measured based on the area thereof.

[0070] In addition, tensile specimens and impact specimens were cut at the quarter of the width of each steel plate and mechanical properties thereof were evaluated, and the results are shown in Table 3 below.

[0071] In this case, the tensile specimen was machined into a proportional specimen with a gauge length of 5.65 × V (specimen width × specimen thickness) by setting a specimen width to 25 mm and setting the thickness of the specimen to the thickness of the steel plate such that the specimen length was perpendicular to the rolling direction of the steel sheet, and the yield strength (YS), tensile strength (TS), and total elongation (E1) values were measured through a room temperature tensile test.

[0072] In addition, the impact specimen was machined into an ASTM E 23 Type A standard specimen (however, a steel plate with a thickness of 8 mm was machinedinto subsize specimens (10 mm × 7.5 mm)) such that the length of the specimen was perpendicular to the rolling direction of the steel plate, and then subjected to an impact test at -40°C, which was represented as the average of the energy values measured from three specimens.

[Table 3]

Division	Microstructure			Mechanical Physical Property			
	Average Grain Size of Ferrite (μm)	Fraction of Pearlite (areal)	Fraction of Bainite (areal)	Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongat ion (%)	Impact Toughness (-40°C, J)
Inventive Example 1	7.2	22	1	374	537	33	211
Inventive Example 2	7.8	17	1	367	521	35	179
Inventive Example 3	5.5	15	0	398	523	37	311
Inventive Example 4	4.7	14	0	382	518	35	327
Inventive Example 5	6.1	10	1	375	519	36	336

(continued)

Division	Microstructure			Mechanical Physical Property			
	Average Grain Size of Ferrite (μm)	Fraction of Pearlite (areal)	Fraction of Bainite (areal)	Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongat ion (%)	Impact Toughness (-40°C, J)
Inventive Example 6	4.4	6	0	402	511	38	385
Inventive Example 7	3.8	18	0	385	521	33	299
Inventive Example 8	2.6	16	0	419	520	36	312
Inventive Example 9	2.8	14	0	423	528	35	325
Inventive Example 10	2.1	19	1	432	526	35	124
Inventive Example 11	2.3	16	2	416	531	34	132
Comparative Example 1	10.2	29	1	391	569	28	75
Comparative Example 2	7.2	4	0	367	481	34	259
Comparative Example 3	6.3	6	14	425	563	28	277
Comparative Example 4	8.8	7	18	413	565	27	84
Comparative Example 5	4.7	3	21	444	552	29	247
Comparative Example 6	1.7	16	0	489	548	29	297
Comparative Example 7	9.9	20	0	350	506	35	141
Comparative Example 8	9.5	14	1	352	486	34	192

[0073] (In Table 3, except for the fractions of pearlite and bainite, the remainder is polygonal ferrite.)

[0074] As shown in Tables 1 to 3, Inventive Examples 1 to 11 satisfying all of the alloy compositions and manufacturing conditions proposed in the present disclosure may be confirmed that all of the strength, ductility, and low-temperature toughness are secured above the target level.

[0075] On the other hand, in Comparative Example 1 in which the content of C in the alloy compositions was excessive and the temperature when heating the slab was too high, the fraction of the pearlite was high, and the average grain size of the ferrite was coarse, so the elongation and impact energy value were inferior. In addition, Comparative Example 2 in which the content of C in the alloy compositions was insufficient was not able to secure the target level of strength due to the low fraction of pearlite.

[0076] On the other hand, in Comparative Examples 3 to 5 in which water cooling was applied during the cooling after the hot rolling, the bainite phase was excessively formed and the strength was high, while the elongation was inferior to less than 30%. Among these, it may be seen that in the case of Comparative Example 4 where the cumulative reduction ratio is insufficient during the finish rolling, the low-temperature toughness was also inferior.

[0077] Comparative Examples 6 and 7, respectively, correspond to the case where the finish hot rolling temperature deviated from the present disclosure. In Comparative Example 6, the ferrite particle diameter was too small, so the strength was high, but the ductility was inferior. On the other hand, in Comparative Example 7, the ferrite particle diameter was too large, so the strength did not reach the target level.

[0078] In Comparative Example 8, the thickness of the final steel plate was 23 mm, and the air cooling was applied after the hot rolling, but the air cooling rate was relatively slow, so that the strength of the target level could not be secured.

Claims

1. A high-strength steel sheet having excellent ductility and low-temperature toughness, comprising: by wt%, 0.05 to 0.12% of carbon (C), 0.2 to 0.5% of silicon (Si), 1.2 to 1.8% of manganese (Mn), 0.012% or less of phosphorus (P), 0.005% or less of sulfur (S), 0.01 to 0.06% of aluminum (Al), 0.005 to 0.02% of titanium (Ti), 0.01 to 0.03% of niobium (Nb), 0.002 to 0.006% of nitrogen (N), 0.5% or less of nickel (Ni), the balance Fe, and inevitable impurities,

   wherein the steel sheet consisting of polygonal ferrite having an average grain size (circle equivalent diameter) of 2 to 8 μm as a main phase and pearlite in an area fraction of 5 to 25% and bainite in an area fraction of 2% or less, including 0%, as a second phase in a microstructure, and has a thickness of 8 to 15 mm,
   wherein the steel sheet has a yield strength of 355 MPa or more, a tensile strength of 490 MPa or more, and an elongation of 30% or more,
   wherein the steel sheet has an impact toughness of 100 J or more at 40° C,
   wherein the tensile strength and the toughness are measured according to the description.

2. A method for manufacturing of a high-strength steel sheet having excellent ductility and low-temperature toughness, comprising:

   heating a steel slab in a temperature range of 1100 to 1200°C, the steel slab comprising, by wt%, 0.05 to 0.12% of carbon (C), 0.2 to 0.5% of silicon (Si), 1.2 to 1.8% of manganese (Mn), 0.012% or less of phosphorus (P), 0.005% or less of sulfur (S), 0.01 to 0.06% of aluminum (Al) 0.005 to 0.02% of titanium (Ti), 0.01 to 0.03% of niobium (Nb), 0.002 to 0.006% of nitrogen (N), 0.5% or less of nickel (Ni), the balance Fe, and inevitable impurities;
   manufacturing the heated steel slab into a hot-rolled steel plate by rough rolling and finish rolling the heated steel slab; and
   cooling the hot-rolled steel plate,
   wherein the finish rolling is performed in a temperature range of Ar3 + 70°C to Ar3 + 170°C to a thickness of 8 to 15 mm,
   wherein the cooling is air-cooling to room temperature,
   wherein the steel sheet consisting of polygonal ferrite having an average grain size, circle equivalent diameter, of 2 to 8 μm as a main phase and pearlite in an area fraction of 5 to 25% and bainite in an area fraction of 2% or less, including 0%, as a second phase in a microstructure,
   wherein the steel sheet has a yield strength of 355 MPa or more, a tensile strength of 490 MPa or more, and an elongation of 30% or more,
   wherein the steel sheet has an impact toughness of 100 J or more at -40° C,
   wherein the tensile strength and the toughness are measured according to the description.

3. The method of claim 2, wherein the finish rolling is performed such that a cumulative reduction ratio is 60 to 90%.

Patentansprüche

1. Hochfestes Stahlblech mit hervorragender Duktilität und Tieftemperaturzähigkeit, umfassend in Gew.-%: 0,05 bis 0,12 % Kohlenstoff (C), 0,2 bis 0,5 % Silicium (Si), 1,2 bis 1,8 % Mangan (Mn), 0,012 % oder weniger Phosphor (P), 0,005 % oder weniger Schwefel (S), 0,01 bis 0,06 % Aluminium (Al), 0,005 bis 0,02 % Titan (Ti), 0,01 bis 0,03 % Niob (Nb), 0,002 bis 0,006 % Stickstoff (N), 0,5 % oder weniger Nickel (Ni), den Rest Fe und unvermeidliche Verunreinigungen,

   wobei das Stahlblech aus polygonalem Ferrit mit einer durchschnittlichen Korngröße (Kreisäquivalentdurchmesser) von 2 bis 8 μm als Hauptphase und Perlit in einem Flächenanteil von 5 bis 25 % und Bainit in einem Flächenanteil von 2 % oder weniger, einschließlich 0 %, als zweite Phase in einer Mikrostruktur besteht und eine Dicke von 8 bis 15 mm aufweist,
   wobei das Stahlblech eine Streckgrenze von 355 MPa oder mehr, eine Zugfestigkeit von 490 MPa oder mehr und eine Dehnung von 30 % oder mehr aufweist,

wobei das Stahlblech eine Schlagzähigkeit von 100 J oder mehr bei -40 °C aufweist,
wobei die Zugfestigkeit und die Zähigkeit gemäß der Beschreibung gemessen werden.

2. Verfahren zur Herstellung eines hochfesten Stahlblechs mit hervorragender Duktilität und Tieftemperaturzähigkeit, umfassend:

Erwärmen einer Stahlbramme in einem Temperaturbereich von 1100 bis 1200 °C, wobei die Stahlbramme in Gew.-% Folgendes umfasst: 0,05 bis 0,12 % Kohlenstoff (C), 0,2 bis 0,5 % Silicium (Si), 1,2 bis 1,8 % Mangan (Mn), 0,012 % oder weniger Phosphor (P), 0,005 % oder weniger Schwefel (S), 0,01 bis 0,06 % Aluminium (Al), 0,005 bis 0,02 % Titan (Ti), 0,01 bis 0,03 % Niob (Nb), 0,002 bis 0,006 % Stickstoff (N), 0,5 % oder weniger Nickel (Ni), den Rest Fe und unvermeidliche Verunreinigungen;
Verarbeiten der erwärmten Stahlbramme zu einer warmgewalzten Stahlplatte durch Vorwalzen und Fertigwalzen der erwärmten Stahlbramme; und
Abkühlen der warmgewalzten Stahlplatte,
wobei das Fertigwalzen in einem Temperaturbereich von Ar3 + 70 °C bis Ar3 + 170 °C zu einer Dicke von 8 bis 15 mm durchgeführt wird,
wobei es sich bei dem Abkühlen um Luftkühlen auf Raumtemperatur handelt,
wobei das Stahlblech aus polygonalem Ferrit mit einer durchschnittlichen Korngröße, Kreisäquivalentdurchmesser, von 2 bis 8 μm als Hauptphase und Perlit in einem Flächenanteil von 5 bis 25 % und Bainit in einem Flächenanteil von 2 % oder weniger, einschließlich 0 %, als zweite Phase in einer Mikrostruktur besteht,
wobei das Stahlblech eine Streckgrenze von 355 MPa oder mehr, eine Zugfestigkeit von 490 MPa oder mehr und eine Dehnung von 30 % oder mehr aufweist,
wobei das Stahlblech eine Schlagzähigkeit von 100 J oder mehr bei -40 °C aufweist,
wobei die Zugfestigkeit und die Zähigkeit gemäß der Beschreibung gemessen werden.

3. Verfahren nach Anspruch 2, wobei das Fertigwalzen derart durchgeführt wird, dass ein kumulatives Reduktionsverhältnis 60 bis 90 % beträgt.

Revendications

1. Tôle d'acier à haute résistance présentant une excellente ductilité et une excellente ténacité à basse température, comprenant : en % en poids, 0,05 à 0,12 % de carbone (C), 0,2 à 0,5 % de silicium (Si), 1,2 à 1,8 % de manganèse (Mn), 0,012 % ou moins de phosphore (P), 0,005 % ou moins de soufre (S), 0,01 à 0,06 % d'aluminium (Al), 0,005 à 0,02 % de titane (Ti), 0,01 à 0,03 % de niobium (Nb), 0,002 à 0,006 % d'azote (N), 0,5 % ou moins de nickel (Ni), le reste de Fe, et des impuretés inévitables,

la tôle d'acier étant constituée de ferrite polygonale ayant une taille moyenne de grain (diamètre équivalent de cercle) de 2 à 8 μm en tant que phase principale et de perlite dans une fraction d'aire de 5 à 25 % et de bainite dans une fraction d'aire de 2 % ou moins, y compris 0 %, en tant que seconde phase dans une microstructure, et a une épaisseur de 8 à 15 mm,
la tôle d'acier ayant une limite d'élasticité de 355 MPa ou plus, une résistance à la traction de 490 MPa ou plus, et un allongement de 30 % ou plus,
la tôle d'acier ayant une résilience de 100 J ou plus à -40 °C,
dans laquelle la résistance à la traction et la ténacité sont mesurées selon la description.

2. Procédé de fabrication d'une tôle d'acier à haute résistance présentant une excellente ductilité et une excellente ténacité à basse température, comprenant :

le chauffage d'une brame d'acier dans une plage de températures de 1100 à 1200 °C, la brame d'acier comprenant, en % en poids, 0,05 à 0,12 % de carbone (C), de 0,2 à 0,5 % de silicium (Si), 1,2 à 1,8 % de manganèse (Mn), 0,012 % ou moins de phosphore (P), 0,005 % ou moins de soufre (S), 0,01 à 0,06 % d'aluminium (Al), 0,005 à 0,02 % de titane (Ti), 0,01 à 0,03 % de niobium (Nb), 0,002 à 0,006 % d'azote (N), 0,5 % ou moins de nickel (Ni), le reste de Fe, et des impuretés inévitables ;
la fabrication de la brame d'acier chauffée en une plaque d'acier laminée à chaud par laminage grossier et laminage de finition de la brame d'acier chauffée ; et
le refroidissement de la plaque d'acier laminée à chaud,
dans lequel le laminage de finition est effectué dans une plage de températures de Ar3 + 70 °C à Ar3 + 170 °C

pour une épaisseur de 8 à 15 mm,
dans lequel le refroidissement est un refroidissement à l'air jusqu'à température ambiante,
dans lequel la tôle d'acier est constituée de ferrite polygonale ayant une taille moyenne de grain, diamètre équivalent de cercle, de 2 à 8 μm en tant que phase principale et de perlite dans une fraction d'aire de 5 à 25 % et de bainite dans une fraction d'aire de 2 % ou moins, y compris 0 %, en tant que seconde phase dans une microstructure,
dans lequel la tôle d'acier a une limite d'élasticité de 355 MPa ou plus, une résistance à la traction de 490 MPa ou plus, et un allongement de 30 % ou plus,
dans lequel la tôle d'acier a une résilience de 100 J ou plus à -40 °C,
dans lequel la résistance à la traction et la ténacité sont mesurées selon la description.

3. Procédé selon la revendication 2, dans lequel le laminage de finition est effectué de sorte qu'un taux de réduction cumulé est de 60 à 90 %.

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

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