US 20160076124A1

(19) United States

(12) Patent Application Publication

(10) Pub. No.: US 2016/0076124 A1

(43) Pub. Date: Mar. 17, 2016

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(54) **HIGH STRENGTH HOT ROLLED STEEL SHEET AND METHOD FOR MANUFACTURING THE SAME (AS AMENDED)**

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(21) Appl. No.: **14/784,455**

(22) PCT Filed: **Mar. 17, 2014**

(86) PCT No.: **PCT/JP2014/001509**

§ 371 (c)(1),
(2) Date: **Oct. 14, 2015**

(30) **Foreign Application Priority Data**

Apr. 15, 2013 (JP) 2013-084448
Apr. 15, 2013 (JP) 2013-084450

Publication Classification

(51) **Int. Cl.**

C22C 38/58	(2006.01)
C22C 38/50	(2006.01)
C22C 38/46	(2006.01)
C22C 38/06	(2006.01)
C22C 38/02	(2006.01)
C22C 38/00	(2006.01)
C22C 38/16	(2006.01)
C22C 38/14	(2006.01)
C22C 38/12	(2006.01)
C22C 38/04	(2006.01)
C21D 6/00	(2006.01)
C21D 9/46	(2006.01)
C21D 7/13	(2006.01)
C21D 1/84	(2006.01)
B21B 1/22	(2006.01)

(52) **U.S. Cl.**

CPC . ***C22C 38/58*** (2013.01); ***B21B 1/22*** (2013.01); ***C22C 38/50*** (2013.01); ***C22C 38/46*** (2013.01); ***C22C 38/06*** (2013.01); ***C22C 38/02*** (2013.01); ***C22C 38/002*** (2013.01); ***C22C 38/001*** (2013.01); ***C22C 38/16*** (2013.01); ***C22C 38/14*** (2013.01); ***C22C 38/12*** (2013.01); ***C22C 38/04*** (2013.01); ***C22C 38/005*** (2013.01); ***C21D 6/004*** (2013.01); ***C21D 6/005*** (2013.01); ***C21D 6/008*** (2013.01); ***C21D 9/46*** (2013.01); ***C21D 7/13*** (2013.01); ***C21D 1/84*** (2013.01); *B21B 2001/225* (2013.01)

(57) **ABSTRACT**

A high strength hot rolled steel sheet having a tensile strength TS of 980 MPa or more, has a composition containing, on a percent by mass basis, C: 0.05% or more and 0.18% or less, Si: 1.0% or less, Mn: 1.0% or more and 3.5% or less, P: 0.04% or less, S: 0.006% or less, Al: 0.10% or less, N: 0.008% or less, Ti: 0.05% or more and 0.20% or less, V: more than 0.1% and 0.3% or less, and the balance being Fe and incidental impurities, and has a microstructure including a primary phase and a secondary phase, the primary phase being a bainite phase having an area fraction of more than 85%, the secondary phase being at least one of ferrite phase, martensite phase, and retained austenite phase, the secondary phase having an area fraction of 0% or more and less than 15% in total, the bainite phase having an average lath interval of laths of 400 nm or less, and the laths having an average long axis length of 5.0 μm or less.

HIGH STRENGTH HOT ROLLED STEEL SHEET AND METHOD FOR MANUFACTURING THE SAME (AS AMENDED)

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This is the U.S. National Phase application of PCT/JP2014/001509, filed Mar. 17, 2014, which claims priority to Japanese Patent Application No. 2013-084448, filed Apr. 15, 2013 and Japanese Patent Application No. 2013-084450, filed Apr. 15, 2013, the disclosures of each of these applications being incorporated herein by reference in their entireties for all purposes.

FIELD OF THE INVENTION

[0002] The present invention relates to a high strength hot rolled steel sheet having a tensile strength of 980 MPa or more, which is suitable for a material for structural parts and frameworks of automobiles, frames of trucks, steel pipes, and the like.

BACKGROUND OF THE INVENTION

[0003] In recent years, automobile exhaust gas regulations have been tightened from the viewpoint of global environmental conservation. Under such circumstances, an improvement of fuel efficiency of automobiles, e.g., trucks, has been an important issue and enhancement of strength and reduction in thickness of the material employed have been further required. Along with this, in particular, high strength hot rolled steel sheets have been actively applied to materials for automobile parts.

[0004] Also, in accordance with a demand for further reduction in the construction cost of pipeline, reduction in the material cost of steel pipes have been required. Consequently, instead of UOE steel pipes formed from steel plate, high strength welded steel pipes produced from coil-shaped hot rolled steel sheets with low-price and high productivity, have been noted as transport pipes.

[0005] As described above, demands for high strength hot rolled steel sheets having predetermined strength as materials for automotive parts and materials for steel pipes have increased year after year. In particular, the high strength hot rolled steel sheet having tensile strength: 980 MPa or more is highly expected to serve as a material capable of improving fuel efficiency of automobile by leaps and bounds or a material capable of reducing the construction cost of pipeline to a large extent.

[0006] However, as the strength of the steel sheet increases, the toughness is degraded in general. Therefore, in order to provide the toughness required of automotive parts and steel pipes to the high strength hot rolled steel sheet, various studies have been conducted on the improvement of toughness. In addition, various studies have been conducted on the hole expansion workability of the high strength hot rolled steel sheet for automotive parts.

Toughness

[0007] For example, Patent Literature 1 proposes a hot rolled steel sheet with sheet thickness: 4.0 mm or more and 12 mm or less, having a composition containing, on a percent by mass basis, C: 0.04% to 0.12%, Si: 0.5% to 1.2%, Mn: 1.0% to 1.8%, P: 0.03% or less, S: 0.0030% or less, Al: 0.005% to 0.20%, N: 0.005% or less, Ti: 0.03% to 0.13%, and the balance being Fe and incidental impurities and a microstructure in which the area fraction of bainite phase is more than 95% and the average grain size of the bainite phase is 3 μm or less, wherein a difference between the Vickers hardness at the position at 50 μm from the surface layer and the Vickers hardness at the position one-quarter of the sheet thickness is specified to be 50 or less, and a difference between the Vickers hardness at the position one-quarter of the sheet thickness and the Vickers hardness at the position at one-half of the sheet thickness is specified to be 40 or less. It is mentioned that according to the technology proposed in Patent Literature 1, a high strength hot rolled steel sheet exhibiting excellent toughness and having tensile stress: 780 MPa or more is obtained by specifying the principal phase to be fine bainite and reducing the hardness distribution in the sheet thickness direction.

[0008] Patent Literature 2 proposes a method for manufacturing a steel sheet, including the steps of heating a steel material satisfying, on a percent by mass basis, C: 0.05% to 0.18%, Si: 0.10% to 0.60%, Mn: 0.90% to 2.0%, P: 0.025% or less (excluding 0%), S: 0.015% or less (excluding 0%), Al: 0.001% to 0.1%, and N: 0.002% to 0.01%, and the balance being Fe and incidental impurities, to 950° C. or higher and 1,250° C. or lower, starting rolling, completing the rolling at 820° C. or higher, performing cooling to 600° C. to 700° C. at a cooling rate of 20° C./s or more, performing holding at that temperature range for 10 to 200 seconds or performing slow cooling and, thereafter, performing cooling to 300° C. or lower at a cooling rate of 5° C./s or more, wherein the metal microstructure is specified to be ferrite: 70% to 90%, martensite or a mixed phase of martensite and austenite: 3% to 15%, and the remainder: bainite (including the case of 0%) on an area fraction relative to the whole microstructure basis and, in addition, the average grain size of the above-described ferrite is specified to be 20 μm or less. It is mentioned that according to the technology proposed in Patent Literature 2, a high toughness steel sheet which has a tensile strength of 490 N/mm^2 or more and which exhibits a low yield ratio, where the yield ratio is 70% or less, is obtained by specifying the metal microstructure to be a microstructure including ferrite having fine crystal grains, martensite or a mixed phase of martensite and austenite, and the like.

[0009] Patent Literature 3 proposes a method for manufacturing a thick high strength hot rolled steel sheet, including the steps of subjecting a steel material containing, on a percent by mass basis, C: 0.02% to 0.25%, Si: 1.0% or less, Mn: 0.3% to 2.3%, P: 0.03% or less, S: 0.03% or less, Al: 0.1% or less, Nb: 0.03% to 0.25%, and Ti: 0.001% to 0.10%, where (Ti+Nb/2)/C<4 is satisfied, to hot rolling, applying first cooling after finish rolling of the hot rolling is completed, where accelerated cooling is performed at an average cooling rate of hot-rolled sheet surface of 20° C./s or more and less than martensite formation critical cooling rate until the surface temperature reaches the Ar_3 transformation temperature or lower and the Ms temperature or lower, applying second cooling, where quenching is performed until the sheet thickness center temperature reaches 350° C. or higher and lower than 600° C., performing coiling into the shape of a coil at a coiling temperature of 350° C. or higher and lower than 600° C. on a sheet thickness center temperature basis, and applying third cooling, where at least the position at one-quarter of the sheet thickness in the coil thickness direction to the position at three-quarters of the sheet thickness is held or retained at a temperature range of 350° C. to 600° C. for 30 minutes or more, sequentially. It is mentioned that according to the technology proposed in Patent Literature 3, a material for X65 grade or higher of high strength electric resistance welded steel pipe exhibiting excellent low-temperature toughness is obtained by specifying the microstructure of the hot rolled steel sheet to be a bainite phase or bainitic ferrite phase and, furthermore, adjusting the amount of grain boundary cementite to a specific value or less.

[0010] Hole Expansion Workability

[0011] For example, Patent Literature 4 describes a method for manufacturing a high strength hot rolled steel sheet, including the steps of heating a steel having a composition containing, on a percent by mass basis, C: 0.05% to 0.15%, Si: 0.2% to 1.2%, Mn: 1.0% to 2.0%, P: 0.04% or less, S: 0.005% or less, Ti: 0.05% to 0.15%, Al: 0.005% to 0.10%, N: 0.007% or less, and the balance being Fe and incidental impurities to 1,150° C. to 1,350° C., and preferably higher than 1,200° C. and 1,350° C. or lower, applying hot rolling which is completed at a finishing temperature of 850° C. to 950° C., and preferably higher than 900° C. and 950° C. or lower, applying cooling after the hot rolling is completed, where cooling to 530° C. is performed at an average cooling rate of 30° C./s or more, applying cooling to coiling temperature: 300° C. to 500° C. at an average cooling rate of 100° C./s or more, and performing coiling at that coiling temperature. It is mentioned that, according to this, the stretch flangeability and the fatigue resistance are considerably improved while high strength of TS: 780 MPa or more is maintained by allowing the microstructure to become composed of a bainite single phase having an average grain size of 5 μm or less, and preferably more than 3.0 μm and 5.0 μm or less and allowing 0.02% or more of solid solution Ti to remain. It is mentioned that the microstructure may be composed of 90% or more on an area fraction basis of bainite phase and a secondary phase other than the bainite phase, where the average grain size of the secondary phase is 3 μm or less, instead of the microstructure composed of the bainite single phase.

[0012] Patent Literature 5 describes a method for manufacturing a high strength hot rolled steel sheet, including the steps of subjecting a slab containing, on a percent by mass basis, C: 0.01% to 0.08%, Si: 0.30% to 1.50%, Mn: 0.50% to 2.50%, P: 0.03% or less, S: 0.005% or less, one or two of Ti: 0.01% to 0.20% and Nb: 0.01% to 0.04%, and the balance being Fe and incidental impurities to hot rolling, where the finish rolling temperature is specified to be the Ar_a transformation temperature to 950° C., performing cooling to 650° C. to 800° C. at a cooling rate of 20° C./s or more, performing air cooling for 2 to 15 s, performing further cooling to 350° C. to 600° C. at a cooling rate of 20° C./s or more, and performing coiling. It is mentioned that, according to this, a high strength hot rolled steel sheet having a ferrite bainite two-phase microstructure in which the proportion of ferrite having a grain size of 2 μm or more is 80% or more, having TS: 690 MPa or more, and exhibiting excellent hole expansion property and ductility is obtained. Also, it is mentioned that 0.0005% to 0.01% of one or two of Ca and REM may be contained.

[0013] Patent Literature 6 describes a high strength steel sheet exhibiting excellent hole expansion property and ductility. The high strength steel sheet described in Patent Literature 6 is a steel sheet containing, on a percent by mass basis, C: 0.01% to 0.20%, Si: 1.50% or less, Al: 1.5% or less, Mn: 0.5% to 3.5%, P: 0.2% or less, S: 0.0005% to 0.009%, N: 0.009% or less, Mg: 0.0006% to 0.01%, 0: 0.005% or less, one or two of Ti: 0.01% to 0.20% and Nb: 0.01% to 0.10%, and the balance being Fe and incidental impurities, wherein all three formulae below

$$[Mg\ \%] \geq ([O\ \%]/16 \times 0.8) \times 24 \quad (1)$$

$$[S\ \%] \leq ([Mg\ \%]/24 - [O\ \%]/16 \times 0.8 + 0.00012) \times 32 \quad (2)$$

$$[S\ \%] \leq 0.0075/[Mn\ \%] \quad (3)$$

are satisfied and the microstructure includes a bainite phase as a primary phase. It is mentioned that, according to this, a steel sheet having TS: 980 MPa or more and exhibiting excellent hole expansion property and ductility is produced. It is mentioned that according to the technology proposed in Patent Literature 3, the addition balance between O, Mg, Mn, and S is adjusted to some conditions, (Nb,Ti)N is allowed to become fine and uniform by utilizing composite precipitation of MgO and MgS, fine, uniform voids are generated in a cross-section of a punched hole, stress concentration during hole expansion working is mitigated and, thereby, the hole expansion property is improved.

PATENT LITERATURE

[0014] PTL 1: Japanese Unexamined Patent Application Publication No. 2012-062557

[0015] PTL 2: Japanese Unexamined Patent Application Publication No. 2007-056294

[0016] PTL 3: Japanese Unexamined Patent Application Publication No. 2010-174343

[0017] PTL 4: Japanese Unexamined Patent Application Publication No. 2012-12701

[0018] PTL 5: Japanese Unexamined Patent Application Publication No. 2002-180190

[0019] PTL 6: Japanese Unexamined Patent Application Publication No. 2005-120437

SUMMARY OF THE INVENTION

Toughness

[0020] In the technology proposed in Patent Literature 1, the high strength hot rolled steel sheet having tensile strength: 980 MPa or more is obtained. However, the control of the bainite microstructure is insufficient and, thereby, there is a problem that excellent low-temperature toughness cannot be obtained stably.

[0021] Also, in the technology proposed in Patent Literature 2, the metal microstructure of the steel is specified to be the structure including a ferrite phase as a primary phase, although in the case where the tensile strength is in the 980 MPa class, the toughness of the ferrite phase may be degraded significantly.

[0022] Also, in the technology proposed in Patent Literature 3, an improvement of the low-temperature toughness by controlling the amount of grain boundary cementite is intended, although the hot rolled steel sheet strength is insufficient and, as shown in the example thereof, tensile strength: about 800 MPa is the maximum. In this regard, in the case where a high strength hot rolled steel sheet having tensile strength: 980 MPa or more is obtained on the basis of the technology proposed in Patent Literature 3, it is necessary that the C content be increased. However, the control of the grain boundary cementite becomes difficult as the C content increases, so that excellent toughness cannot be obtained stably in some cases.

[0023] The present invention solves the above-described problems included in the technologies of the related art advantageously, and it is an object to provide a high strength hot rolled steel sheet having high strength of tensile strength: 980 MPa or more, further exhibiting good toughness and, in one example, having a sheet thickness of 4 mm or more and 15 mm or less and a method for manufacturing the same.

[0024] Hole Expansion Property

[0025] In the technology described in Patent Literature 4, the aimed strength is tensile strength TS: 780 MPa or more, and when the C content is increased, high strength of tensile strength TS: 980 MPa or more can be obtained. However, if the C content is increased to further enhance the strength, control of the amount of precipitation of Ti carbides becomes difficult, and there is a problem that 0.02% or more of solid solution Ti required for improving hole expansion property cannot be left easily stably.

[0026] In the technology described in Patent Literature 5, the steel sheet microstructure is specified to be the mixed microstructure of ferrite in which the proportion of ferrite having a grain size of 2 μm or more is 80% or more+bainite. Therefore, there are problems that the resulting steel sheet strength is about 976 MPa at the maximum, further higher strength of tensile strength TS: 980 MPa or more cannot be achieved easily, and even if the high strength of tensile strength TS: 980 MPa or more is obtained, the toughness of the ferrite phase is degraded significantly and excellent hole expansion property cannot be obtained.

[0027] It is mentioned that in the technology described in Patent Literature 6, (Nb,Ti)N is allowed to become fine and uniform, in a cross-section of a punched hole, fine, uniform voids are generated, stress concentration during hole expansion working is mitigated and, thereby, the hole expansion property (hole expansion workability) is improved. However, there are problems that the distances between grains of (Nb, Ti)N are reduced by allowing (Nb,Ti)N to become fine and uniform, voids generated during local deformation are connected easily, and local elongation may be reduced.

[0028] The present invention solves such problems included in the technologies of the related art, and it is an object to provide a high strength hot rolled steel sheet exhibiting excellent hole expansion workability while the high strength of tensile strength: 980 MPa or more has and a method for manufacturing the same. In this regard, the high strength hot rolled steel sheet aimed in the present invention may be a steel sheet having a sheet thickness of 2 to 4 mm.

[0029] Toughness

[0030] In order to achieve the object, the present inventors conducted intensive research to improve the toughness of a hot rolled steel sheet while the high strength of tensile strength TS: 980 MPa or more had. Specifically, the bainite phase was noted, where it is known that the bainite phase has good strength-toughness balance in general, and various factors affecting the strength and the toughness of the hot rolled steel sheet, in which the primary phase of the microstructure was bainite, were studied. As a result, it was found that allowing laths of the bainite phase to become fine was very effective in enhancing strength and improving toughness of the hot rolled steel sheet. Then, further studies were conducted. As a result, it was found that the toughness was improved considerably while the high strength of tensile strength TS: 980 MPa or more was maintained by adding predetermined amounts of Ti and V, specifying the primary phase to be preferably more than 85% on an area fraction basis of bainite phase, specifying the lath interval of the bainite phase to be 400 nm or less in average, and specifying the length of long axis of the lath to be 5.0 μm or less in average.

[0031] The present invention has been completed on the basis of the above-described findings and additional studies. That is, an exemplary configuration of an embodiment of the present invention is as described below.

[1] A high strength hot rolled steel sheet having a tensile strength TS of 980 MPa or more and excellent toughness, comprising a composition and a microstructure,

[0032] the composition containing, on a percent by mass basis, C: 0.05% or more and 0.18% or less, Si: 1.0% or less, Mn: 1.0% or more and 3.5% or less, P: 0.04% or less, S: 0.006% or less, Al: 0.10% or less, N: 0.008% or less, Ti: 0.05% or more and 0.20% or less, V: more than 0.1% and 0.3% or less, and the balance being Fe and incidental impurities, and

[0033] the microstructure comprising a primary phase and a secondary phase,

[0034] the primary phase being a bainite phase having an area fraction of more than 85%,

[0035] the secondary phase being at least one of ferrite phase, martensite phase and retained austenite phase, the secondary phase having an area fraction of 0% or more and less than 15% in total,

[0036] the bainite phase having an average lath interval of laths of 400 nm or less, and the laths having an average long axis length of 5.0 μm or less.

[2] The high strength hot rolled steel sheet having excellent toughness, according to the item [1], wherein the composition further contains, on a percent by mass basis, at least one selected from Nb: 0.005% or more and 0.4% or less, B: 0.0002% or more and 0.0020% or less, Cu: 0.005% or more and 0.2% or less, Ni: 0.005% or more and 0.2% or less, Cr: 0.005% or more and 0.4% or less, and Mo: 0.005% or more and 0.4% or less.

[3] The high strength hot rolled steel sheet having excellent toughness, according to the item [1] or item [2], wherein the composition further contains, on a percent by mass basis, at least one selected from Ca: 0.0002% or more and 0.01% or less and REM: 0.0002% or more and 0.01% or less.

[4] A method for manufacturing a high strength hot rolled steel sheet having excellent toughness, including:

[0037] heating a steel having the composition according to any one of the items [1] to [3] to 1,200° C. or higher,

[0038] applying hot rolling having rough rolling and finish rolling in which the accumulated rolling reduction is 50% or more in a temperature range of 1,000° C. or lower and the finishing temperature is 820° C. or higher and 930° C. or lower,

[0039] starting cooling within 4.0 s after the hot rolling,

[0040] performing cooling at an average cooling rate of 20° C./s or more, and

[0041] performing coiling at a coiling temperature of 300° C. or higher and 450° C. or lower.

[0042] Hole Expansion Workability

[0043] In order to achieve the object, the present inventors conducted intensive research on various factors affecting the hole expansion workability while the high strength of tensile strength TS: 980 MPa or more has. As a result, it was found that when the primary phase in the microstructure was specified to be the bainite phase and high strength of tensile strength TS: 980 MPa or more had, cementite functioned as a starting point of void formation during hole expansion working or local deformation, and as the amount of cementite increased, voids were connected to each other easily, the local ductility was degraded, and the hole expansion workability was degraded. Also, it was found that as the grain size of cementite increased, coarse voids were formed in the punched surface by punching, which was a pretreatment of hole expansion working, and the hole expansion property was degraded.

[0044] Under these circumstances, the present inventors conducted further research and found that in order to improve the hole expansion property and, furthermore, the local ductility while the high strength of tensile strength TS: 980 MPa or more had, adjustment of the balance between the contents of C, Si, Ti, and V, further adjustment of cementite to 0.8% or less on a percent by mass basis and the average grain size of cementite to 150 nm or less by optimizing the production condition, and an increase in distance between cementite grains were important.

[0045] The present invention has been completed on the basis of the above-described findings and additional studies. That is, the gist of an exemplary embodiment of the present invention is as described below.

[5] A high strength hot rolled steel sheet having a tensile strength TS of 980 MPa or more and an excellent hole expansion property, comprising a composition and a microstructure,

[0046] the composition containing, on a percent by mass basis, C: more than 0.1% and 0.2% or less, Si: 1.0% or less, Mn: 1.5% to 2.5%, P: 0.05% or less, S: 0.005% or less, Al: 0.10% or less, N: 0.007% or less, Ti: 0.07% to 0.2%, V: more than 0.1% and 0.3% or less, and the balance being Fe and incidental impurities,

[0047] the microstructure comprising a primary phase and the remainder other than the primary phase,

[0048] the primary phase being a bainite phase having an area fraction of 90% or more,

[0049] the remainder being at least one selected from martensite phase, austenite phase and ferrite phase, and having an area fraction 10% or less, and

[0050] cementite dispersed in the microstructure having a mass percent of 0.8% or less and an average grain size of 150 nm or less. [6] The high strength hot rolled steel sheet according to the item [5], wherein the composition further contains, on a percent by mass basis, at least one selected from Nb: 0.005% to 0.1%, B: 0.0002% to 0.002%, Cu: 0.005% to 0.3%, Ni: 0.005% to 0.3%, Cr: 0.005% to 0.3%, and Mo: 0.005% to 0.3%.

[7] The high strength hot rolled steel sheet according to the item [5] or item [6], wherein the composition further contains, on a percent by mass basis, at least one selected from Ca: 0.0003% to 0.01% and REM: 0.0003% to 0.01%.

[8] A method for manufacturing a high strength hot rolled steel sheet having excellent hole expansion property, including: heating a steel material, applying hot rolling having rough rolling and finish rolling, applying cooling having two stages of first stage cooling and second stage cooling, and performing coiling to produce a hot rolled steel sheet,

[0051] wherein

[0052] the steel material is specified to be a steel material having a composition containing, on a percent by mass basis, C: more than 0.1% and 0.2% or less, Si: 1.0% or less, Mn: 1.5% to 2.5%, P: 0.05% or less, S: 0.005% or less, Al: 0.10% or less, N: 0.007% or less, Ti: 0.07% to 0.2%, V: more than 0.1% and 0.3% or less, and the balance being Fe and incidental impurities,

[0053] the heating is a treatment to heat the steel material to 1,200° C. or higher,

[0054] the finish rolling is rolling with finishing temperature: 850° C. to 950° C.,

[0055] the first stage cooling is cooling in which cooling is started within 1.5 s of completion of the above-described finish rolling and cooling to a first stage cooling stop temperature of 500° C. to 600° C. is performed at an average cooling rate of 20° C./s to 80° C./s,

[0056] the second stage cooling is cooling in which cooling to a second stage cooling stop temperature of 330° C. to 470° C. is performed at an average cooling rate of 90° C./s or more within 3 s of completion of the above-described first stage cooling, and

[0057] after completion of the second stage cooling, coiling is performed, where the coiling temperature is the second stage cooling stop temperature.

[9] The method for manufacturing a high strength hot rolled steel sheet, according to the item [8], wherein the composition further contains, on a percent by mass basis, at least one selected from Nb: 0.005% to 0.1%, B: 0.0002% to 0.002%, Cu: 0.005% to 0.3%, Ni: 0.005% to 0.3%, Cr: 0.005% to 0.3%, and Mo: 0.005% to 0.3%.

[10] The method for manufacturing a high strength hot rolled steel sheet, according to the item [8] or item [9], wherein the composition further contains, on a percent by mass basis, at least one selected from Ca: 0.0003% to 0.01% and REM: 0.0003% to 0.01%.

[0058] Toughness

[0059] According to an aspect of the present invention, a high strength hot rolled steel sheet having a tensile strength of 980 MPa or more and exhibiting excellent toughness is obtained. Therefore, the car body weight can be reduced while the safety of the automobile is ensured and an environmental load can be reduced by applying the present invention to structural parts and frameworks of automobiles, frames of trucks, and the like. In the case where a welded steel pipe produced from the hot rolled steel sheet according to the present invention serving as a material instead of the UOE pipe produced from a steel plate serving as a material is applied to a transport pipe, the productivity is improved and the cost can be further reduced.

[0060] Also, the present invention can stably produce a hot rolled steel sheet exhibiting improved toughness while high strength of tensile strength: 980 MPa or more has and, therefore, is very useful for the industry.

[0061] Hole Expansion Workability

[0062] According to an aspect of the present invention, a hot rolled steel sheet exhibiting considerably improved hole expansion workability can be produced while high strength of tensile strength: 980 MPa or more has, so that an industrially remarkable effect is exerted. Also, effects that the car body weight can be reduced while the safety of the automobile is ensured and an environmental load can be reduced are exerted by applying the hot rolled steel sheet according to an embodiment of the present invention to materials for chassis parts, structural parts and frameworks of automobiles, frames of trucks, and the like.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

First Embodiment

Toughness

[0063] A first embodiment will be specifically described below.

[0064] To begin with, reasons for the limitation of the chemical composition of the hot rolled steel sheet according to an aspect of the present invention will be described. Hereafter the term "%" representing the chemical composition refers to "percent by mass" unless otherwise specified.

[0065] C: 0.05% or more and 0.18% or less

[0066] C enhances the strength of the steel and facilitates formation of bainite. Therefore, in an embodiment of the present invention, it is useful that the C content be 0.05% or more. On the other hand, if the C content is more than 0.18%, formation control of bainite becomes difficult, formation of hard martensite increases, and the toughness of the hot rolled steel sheet is degraded. Consequently, the C content may be specified to be 0.05% or more and 0.18% or less, preferably 0.08% or more and 0.17% or less, and more preferably more than 0.10% and 0.16% or less. In this regard, in the case where the amount of Mn is 2.5% or more and 3.5% or less, the amount of C is preferably 0.06% or more and 0.15% or less.

[0067] Si: 1.0% or less

[0068] Si is an element which suppresses coarse oxides and cementite to impair the toughness and which contributes to solute strengthening. If the content is more than 1.0%, the surface quality of the hot rolled steel sheet can be degraded significantly and degradation in the chemical conversion treatability and the corrosion resistance is caused. Therefore, the Si content may be specified to be 1.0% or less, and preferably 0.4% or more and 0.8% or less.

[0069] Mn: 1.0% or more and 3.5% or less

[0070] Mn is an element which contributes to enhancement of strength of the steel through solid solution and which facilitates formation of bainite through improvement of the hardenability. In order to obtain such effects, it is beneficial that the Mn content be 1.0% or more. On the other hand, if the Mn content is more than 3.5%, center segregation becomes considerable, and the toughness of the hot rolled steel sheet is degraded. Therefore, the Mn content may be specified to be 1.0% or more and 3.5% or less. In this regard, 1.5% or more and 3.0% or less is preferable and 1.8% or more and 2.5% or less is more preferable.

[0071] P: 0.04% or less

[0072] P is an element which contributes to enhancement of strength of the steel through solid solution but is an element which segregates at grain boundaries, in particular prior-austenite grain boundaries, to cause degradation in low-temperature toughness and workability. Consequently, it is preferable that the P content be minimized, although the content up to 0.04% can be allowable. Therefore, the P content may be specified to be 0.04% or less. However, when the P content is excessively reduced, an effect corresponding to an increase in the smelting cost is not obtained, so that the P content is specified to be preferably 0.003% or more and 0.03% or less, and more preferably 0.005% or more and 0.02% or less.

[0073] S: 0.006% or less

[0074] S forms coarse sulfides by bonding to Ti and Mn and degrades the workability of the hot rolled steel sheet. Consequently, it is preferable that the S content be minimized, although the content up to 0.006% can be allowable. Therefore, the S content may be specified to be 0.006% or less. However, when the S content is excessively reduced, an effect corresponding to an increase in the smelting cost is not obtained, so that the S content is specified to be preferably 0.0003% or more and 0.004% or less, and more preferably 0.0005% or more and 0.002% or less.

[0075] Al: 0.10% or less

[0076] Al is an element which functions as a deoxidizing agent and which is effective in improving cleanliness of the steel. On the other hand, excessive addition of Al causes increases in oxide inclusions, degrades the toughness of the hot rolled steel sheet and, in addition, causes an occurrence of flaw. Therefore, the Al content may be specified to be 0.10% or less, preferably 0.005% or more and 0.08% or less, and further preferably 0.01% or more and 0.05% or less.

[0077] N: 0.008% or less

[0078] Ni precipitates as nitrides by bonding to nitride-forming elements and contributes to making crystal grains fine. However, N bonds to Ti at a high temperature to form coarse nitrides easily and degrades the toughness of the hot rolled steel sheet. Consequently, the N content may be specified to be 0.008% or less, preferably 0.001% or more and 0.006% or less, and more preferably 0.002% or more and 0.005% or less.

[0079] Ti: 0.05% or more and 0.20% or less

[0080] Ti is a beneficial element in an embodiment of the present invention. Ti contributes to enhancement of strength of the steel through formation of carbonitrides to make crystal grains fine and through precipitation strengthening. Also, Ti forms many fine (Ti,V)C clusters at low temperatures of 300° C. or higher and 450° C. or lower, reduces the amount of cementite in the steel, and improve the toughness of the hot rolled steel sheet. In order to exert such effects, it is advantageous that the Ti content be 0.05% or more. On the other hand, if the Ti content is excessive and is more than 0.20%, the above-described effects are saturated, an increase in coarse precipitates is caused, and degradation in the toughness of the hot rolled steel sheet is caused. Therefore, the Ti content may be limited to within the range of 0.05% or more and 0.20% or less, and preferably 0.08% or more and 0.15% or less.

[0081] V: more than 0.1% and 0.3% or less

[0082] V is a beneficial element in an embodiment of the present invention. V contributes to enhancement of strength of the steel through formation of carbonitrides to make crystal grains fine and through precipitation strengthening. Also, V improves the hardenability and contributes to formation and making fine of bainite phase. In addition, V forms many fine (Ti,V)C clusters at low temperatures of 300° C. or higher and 450° C. or lower, reduces the amount of cementite in the steel, and improves the toughness of the hot rolled steel sheet. In order to exert such effects, it is advantageous that the V content be more than 0.1%. On the other hand, if the V content is excessive and is more than 0.3%, the above-described effects are saturated, so that the cost increases. Therefore, the V content may be limited to within the range of more than 0.1% and 0.3% or less, and preferably 0.15% or more and 0.25% or less.

[0083] The basic components of the hot rolled steel sheet according to an aspect of the present invention are as described above. The hot rolled steel sheet according to embodiments of the present invention may further contain, as necessary, at least one selected from Nb: 0.005% or more and 0.4% or less, B: 0.0002% or more and 0.0020% or less, Cu:

0.005% or more and 0.2% or less, Ni: 0.005% or more and 0.2% or less, Cr: 0.005% or more and 0.4% or less, and Mo: 0.005% or more and 0.4% or less for the purpose of, for example, improvement of toughness and enhancement of strength.

[0084] Nb: 0.005% or more and 0.4% or less

[0085] Nb is an element which contributes to enhancement of strength of the steel through formation of carbonitrides. In order to exert such an effect, it is preferable that the Nb content be 0.005% or more. On the other hand, if the Nb content is more than 0.4%, deformation resistance increases, so that a rolling force of hot rolling increases in production of the hot rolled steel sheet, a load to a rolling mill becomes too large, and rolling operation in itself may become difficult. Meanwhile, if the Nb content is more than 0.4%, coarse precipitates are formed and the toughness of the hot rolled steel sheet tends to be degraded. Therefore, the Nb content is preferably specified to be 0.005% or more and 0.4% or less. In this regard, 0.01% or more and 0.3% or less is more preferable and 0.02% or more and 0.2% or less is further preferable.

[0086] B: 0.0002% or more and 0.0020% or less

[0087] B is an element which segregates at austenite grain boundaries and which suppresses formation and growth of ferrite. Also, B is an element which improves the hardenability and which contributes to formation and making fine of bainite phase. In order to exert these effects, it is preferable that the B content be 0.0002% or more. However, if the B content is more than 0.0020%, formation of martensite phase is facilitated, so that the toughness of the hot rolled steel sheet may be degraded significantly. Therefore, in the case where B is contained, the content thereof is specified to be preferably 0.0002% or more and 0.0020% or less. In this regard, 0.0004% or more and 0.0012% or less is more preferable.

[0088] Cu: 0.005% or more and 0.2% or less

[0089] Cu is an element which contributes to enhancement of strength of the steel through solid solution. Also, Cu is an element which has a function of improving hardenability, which lowers, in particular, the bainite transformation temperature, and which contributes to making bainite phase fine. In order to obtain these effects, it is preferable that the Cu content be 0.005% or more, although if the content thereof is more than 0.2%, degradation in the surface quality of the hot rolled steel sheet is caused. Therefore, the Cu content is specified to be preferably 0.005% or more and 0.2% or less. In this regard, 0.01% or more and 0.15% or less is more preferable.

[0090] Ni: 0.005% or more and 0.2% or less

[0091] Ni is an element which contributes to enhancement of strength of the steel through solid solution. Also, Ni has a function of improving hardenability and facilitates formation of bainite phase. In order to obtain these effects, it is preferable that the Ni content be 0.005% or more. However, if the Ni content is more than 0.2%, a martensite phase is generated easily, and the toughness of the hot rolled steel sheet may be degraded significantly. Therefore, the Ni content is specified to be preferably 0.005% or more and 0.2% or less, and more preferably 0.01% or more and 0.15% or less.

[0092] Cr: 0.005% or more and 0.4% or less

[0093] Cr forms carbides and contributes to enhancement of strength of the hot rolled steel sheet. In order to exert this effect, it is preferable that the Cr content be 0.005% or more. On the other hand, if the Cr content is excessive and is more than 0.4%, it is feared that the corrosion resistance of the hot rolled steel sheet is degraded. Therefore, the Cr content is specified to be preferably 0.005% or more and 0.4% or less, and more preferably 0.01% or more and 0.2% or less.

[0094] Mo: 0.005% or more and 0.4% or less

[0095] Mo facilitates formation of bainite phase through improvement of the hardenability and contributes to improvement of the toughness and enhancement of strength of the hot rolled steel sheet. In order to obtain such effects, it is preferable that the Mo content be 0.005% or more. However, if the Mo content is more than 0.4%, a martensite phase is generated easily, and the toughness of the hot rolled steel sheet may be degraded. Therefore, the Mo content is specified to be preferably 0.005% or more and 0.4% or less, and more preferably 0.01% or more and 0.2% or less.

[0096] Meanwhile, the hot rolled steel sheet according to the present invention may contain, as necessary, one or two selected from Ca: 0.0002% or more and 0.01% or less and REM: 0.0002% or more and 0.01% or less.

[0097] Ca: 0.0002% or more and 0.01% or less

[0098] Ca is effective in controlling the shape of sulfide inclusions and improving bending workability and the toughness of the hot rolled steel sheet. In order to exert these effects, it is preferable that the Ca content be 0.0002% or more. However, if the Ca content is more than 0.01%, surface defects of the hot rolled steel sheet may be caused. Therefore, the Ca content is specified to be preferably 0.0002% or more and 0.01% or less. In this regard, 0.0004% or more and 0.005% or less is more preferable.

[0099] REM: 0.0002% or more and 0.01% or less

[0100] As with Ca, REM controls the shape of sulfide inclusions and improves adverse influences of sulfide inclusions on the bending workability and the toughness of the hot rolled steel sheet. In order to exert these effects, it is preferable that the REM content be 0.0002% or more. However, if the REM content is excessive and is more than 0.01%, the cleanliness of the steel tends to be degraded and the toughness of the hot rolled steel sheet tends to be degraded. Therefore, in the case where REM is contained, the content thereof is specified to be preferably 0.0002% or more and 0.01% or less. In this regard, 0.0004% or more and 0.005% or less is more preferable.

[0101] In an embodiment of the present invention, the remainder other than those described above is composed of Fe and incidental impurities. Examples of incidental impurities include Sb, Sn, and Zn. As for contents of them, Sb: 0.01% or less, Sn: 0.1% or less, and Zn: 0.01% or less are allowable.

[0102] Next, reasons for the limitation of the microstructure of the hot rolled steel sheet according to an aspect of the present invention will be described.

[0103] The hot rolled steel sheet according to an embodiment the present invention has a microstructure in which a primary phase is more than 85% on an area fraction basis of bainite phase, a secondary phase is at least one of ferrite phase, martensite phase, and retained austenite phase, 0% or more and less than 15% in total on an area fraction basis of secondary phase is contained, the average lath interval of laths of the above-described bainite phase may be 400 nm or less, and the average long axis length of the above-described laths may be 5.0 μm or less.

[0104] Fraction of bainite phase: more than 85% on an area fraction basis

[0105] The primary phase of the hot rolled steel sheet according to an embodiment of the present invention is a bainite phase having excellent strength-toughness balance. If the fraction of the bainite phase is 85% or less on an area fraction basis, a hot rolled steel sheet provided with predetermined strength and toughness may not be obtained. Therefore, the fraction of the bainite phase may be specified to be more than 85% on an area fraction basis, preferably 87% or more, and more preferably 90% or more. It is still more preferable that the fraction of the bainite phase be 100% on an area fraction basis and the microstructure be a bainite single phase microstructure.

[0106] Fraction of at least one of ferrite phase, martensite phase, and retained austenite phase (secondary phase): 0% or more and less than 15% in total on an area fraction basis

[0107] The hot rolled steel sheet according to an embodiment of the present invention may include a secondary phase, which is composed of at least one of ferrite phase, martensite phase, and retained austenite phase, as a microstructure other than the bainite phase serving as the primary phase. The microstructure is specified to be preferably a bainite single phase microstructure to impart predetermined strength and toughness to the hot rolled steel sheet. However, even in the case where at least one of ferrite phase, martensite phase, and retained austenite phase is included as the secondary phase, the total fraction of them of less than 15% on an area fraction basis is allowable. Therefore, the fraction of the above-described secondary phase in total is specified to be 0% or more and less than 15% on an area fraction basis, preferably 13% or less, and more preferably 11% or less.

[0108] Average lath interval of laths of bainite phase: 400 nm or less

[0109] Average long axis length of laths of bainite phase: 5.0 μm or less

[0110] It is very beneficial for enhancement of strength and enhancement of toughness of the hot rolled steel sheet to make laths of bainite phase fine. The present inventors found that the sizes of laths of bainite phase, specifically, the lath interval and the long axis length of the lath, were factors which influenced greatly the strength and the toughness of the hot rolled steel sheet. Consequently, in aspects of the present invention, predetermined strength and toughness are added to the hot rolled steel sheet by specifying the lath interval and the long axis length of the lath of bainite phase.

[0111] In the case where the average lath interval of laths of the bainite phase is more than 400 nm or the average long axis length of laths of the bainite phase is more than 5.0 μm, a hot rolled steel sheet exhibiting predetermined strength and toughness according to an embodiment of the present invention in combination may not be obtained. Therefore, the average lath interval of laths of the bainite phase may be specified to be 400 nm or less, and preferably 350 nm or less. Also, the average long axis length of laths of the bainite phase is specified to be 5.0 μm or less, and preferably 4.0 μm or less. In this regard, lower limits of the average lath interval of laths of the bainite and the average long axis length of laths of the bainite phase are not particularly specified. The lath interval and the long axis length are determined on the basis of the bainite transformation temperature and, therefore, usually the average lath interval of laths of the bainite phase is 100 nm or more and the average long axis length of laths of the bainite phase is 1.0 μm or more.

[0112] A high strength hot rolled steel sheet having a tensile strength of 980 MPa or more and having toughness required of a material for structural parts of automobiles and a material for steel pipes, e.g., line pipes, is obtained by specifying the composition and the microstructure, as described above. In this regard, the sheet thickness of the hot rolled steel sheet according to the present invention is not specifically limited, although the sheet thickness is specified to be preferably about 4 mm or more and 15 mm or less.

[0113] Next, a preferable method for manufacturing the hot rolled steel sheet according to an aspect of the present invention will be described.

[0114] Embodiments of the present invention may be characterized by heating a steel having the above-described composition to 1,200° C. or higher, applying hot rolling composed of rough rolling and finish rolling in which the accumulated rolling reduction is 50% or more in a temperature range of 1,000° C. or lower and the finishing temperature is 820° C. or higher and 930° C. or lower, starting cooling within 4.0 s of the hot rolling, performing cooling at an average cooling rate of 20° C./s or more, and performing coiling at a coiling temperature of 300° C. or higher and 450° C. or lower.

[0115] The method for manufacturing a steel is not necessarily particularly limited, and any common method can be applied, wherein a molten steel having the above-described composition is refined in a converter or the like, and a steel, e.g., a slab, is produced by a casting method, e.g., a continuous casting method. In this regard, an ingot-making and blooming method may be used.

[0116] Meanwhile, in one embodiment of the present invention, electro-magnetic stirrer (EMS), intentional bulging soft reduction casting (IBSR), and the like can be applied to reduce component segregation of the steel during continuous casting. Equiaxial crystals are formed in the sheet thickness center portion by applying an electro-magnetic stirrer treatment, so that segregation can be reduced. Also, in the case where the intentional bulging soft reduction casting is applied, segregation in the sheet thickness center portion can be reduced by preventing flowing of the molten steel in an unsolidified portion of the continuous casting slab. The toughness described below can be brought to a more excellent level by applying at least one of these segregation reduction treatments.

[0117] Heating temperature of steel: 1,200° C. or higher

[0118] In steel material, e.g., a slab, most of carbonitride-forming elements, e.g., Ti, are present as coarse carbonitrides. The presence of these coarse nonuniform precipitates causes degradation in various characteristics (for example, strength, toughness, and hole expansion workability) of the hot rolled steel sheet. Consequently, the steel material before hot rolling is heated to allow coarse precipitates to form solid solutions. In order to allow these coarse precipitates to form solid solutions sufficiently, it is advantageous that the heating temperature of the steel be 1,200° C. or higher. However, if the heating temperature of the steel is too high, an occurrence of slab flaw and reduction in yield due to scale-off are caused. Therefore, the heating temperature of the steel is specified to be preferably 1,350° C. or lower, and more preferably 1,220° C. or higher and 1,300° C. or lower.

[0119] In this regard, the steel material may be heated to the heating temperature of 1,200° C. or higher and is held for a predetermined time. If the holding time is more than 4,800 seconds, the amount of generation of scale increases and, as a result, scale biting and the like occurs easily in the following hot rolling step, and the surface quality of the hot rolled steel sheet tends to be degraded. Therefore, the holding time of the steel material in the temperature range of 1,200° C. or higher is specified to be preferably 4,800 seconds or less, and more preferably 4,000 seconds or less.

[0120] Following the heating of the steel material, the steel material may be subjected to hot rolling having rough rolling and finish rolling. The condition of the rough rolling is not specifically limited insofar as predetermined sheet bar dimensions are ensured. Following the rough rolling, the finish rolling is applied. In this regard, preferably, descaling is performed before the finish rolling or between stands during rolling. In the finish rolling, the accumulated rolling reduction may be specified to be 50% or more in a temperature range of 1,000° C. or lower and the finishing temperature may be specified to be 820° C. or higher and 930° C. or lower.

[0121] Accumulated rolling reduction in temperature range of 1,000° C. or lower: 50% or more

[0122] In order to make laths of the bainite phase fine, it is advantageous that the rolling reduction in a relatively low temperature range be increased and crystal grains after rolling be allowed to become crystal grains elongated in the rolling direction (crystal grains having a high elongation rate). If the accumulated rolling reduction at 1,000° C. or lower is less than 50%, it becomes difficult to make bainite having a predetermined lath structure (e.g., average lath interval: 400 nm or less, average long axis length: 5.0 μm or less), and the toughness of the hot rolled steel sheet is degraded. Therefore, the accumulated rolling reduction at 1,000° C. or lower may be specified to be 50% or more, and preferably 60% or more. However, if the accumulated rolling reduction in a temperature range of 1,000° C. or lower is excessively high, crystal grains are excessively elongated in the rolling direction and ferrite is generated easily, so that it may also be difficult to make bainite having a predetermined lath structure. Consequently, the accumulated rolling reduction in a temperature range of 1,000° C. or lower is specified to be preferably 80% or less.

[0123] Finishing temperature: 820° C. or higher and 930° C. or lower

[0124] If the finishing temperature of the finishing rolling is lower than 820° C., rolling is performed at a temperature of two-phase region of ferrite+austenite, so that a deformation microstructure remains after rolling and the toughness of the hot rolled steel sheet is degraded. On the other hand, if the finishing temperature is higher than 930° C., austenite grains grow, and a bainite phase of the hot rolled steel sheet obtained after cooling is coarsened. As a result, it becomes difficult to make a predetermined microstructure, and the toughness of the hot rolled steel sheet is degraded. Therefore, the finishing temperature may be specified to be 820° C. or higher and 930° C. or lower, and preferably 840° C. or higher and 920° C. or lower. Here, the finishing temperature refers to the surface temperature of a sheet.

[0125] Start of forced cooling: within 4.0 s of completion of finish rolling

[0126] Forced cooling may be started within 4.0 s of, preferably just after, completion of the finish rolling, cooling may be stopped at the coiling temperature, and coiling into the shape of a coil is performed. If the time from completion of the finish rolling to start of the forced cooling is more than 4.0 s and is long, austenite grains become coarse, and a bainite phase is coarsened. Also, austenite grains become coarse, so that the hardenability of the steel sheet increases and a martensite phase is generated easily. In the case where the bainite phase is coarsened and the martensite phase is generated easily, predetermined excellent toughness may not be obtained. Therefore, the forced cooling start time is limited to within 4.0 s of completion of the finish rolling.

[0127] Average cooling rate: 20° C./s or more

[0128] If the average cooling rate from the finishing temperature to the coiling temperature is less than 20° C./s, a bainite phase having a predetermined area fraction may not be obtained. Therefore, the above-described average cooling rate may be specified to be 20° C./s or more, and preferably 30° C./s or more. The upper limit of the average cooling rate is not particularly specified. However, if the average cooling rate is too large, the surface temperature becomes too low, and martensite is generated on the steel sheet surface easily. Therefore, the average cooling rate is specified to be preferably 60° C./s or less. In this regard, the above-described average cooling rate is specified to be an average cooling rate of the steel sheet surface.

[0129] Coiling temperature: 300° C. or higher and 450° C. or lower

[0130] If the coiling temperature is lower than 300° C., hard martensite phase and retained austenite phase are formed in the microstructure of the inside of the steel sheet. As a result, the hot rolled steel sheet may not be made a predetermined microstructure and predetermined toughness may not be obtained. On the other hand, if the coiling temperature is more than 450° C., ferrite and pearlite increase in the microstructure of the inside of the steel sheet. As a result, the lath interval of the bainite phase increases and, thereby, the toughness of the hot rolled steel sheet is degraded significantly. For the above-described reasons, the coiling temperature is specified to be within the range of 300° C. or higher and 450° C. or lower, and preferably 330° C. or higher and 430° C. or lower.

[0131] In this regard, after the coiling, the hot rolled steel sheet may be subjected to temper rolling following the common method or be subjected to pickling to remove scale formed on the surface. Alternatively, a galvanization process, e.g., hot dip galvanizing or electrogalvanizing, and a chemical conversion treatment may further be applied.

Example 1

[0132] A molten steel having the composition shown in Table 1 was refined in a converter, and a slab (steel) was produced by a continuous casting method. In the continuous casting, those other than Hot rolled steel sheet No. 1' of Steel A1 in Tables 1 to 3 described below were subjected to electromagnetic stirrer (EMS) for the purpose of segregation reduction treatment of the components. Subsequently, these steel materials were heated under the conditions shown in Table 2, and were subjected to hot rolling having rough rolling and finish rolling under the conditions shown in Table 2. After the finish rolling was completed, cooling was performed under the conditions shown in Table 2, and coiling was performed at coiling temperatures shown in Table 2, so that hot rolled steel sheets having sheet thicknesses shown in Table 2 were produced.

[0133] Test pieces were taken from the resulting hot rolled steel sheets, and microstructure observation, a tensile test, and a Charpy impact test were performed. The microstructure observation method and various testing methods were as described below.

(i) Microstructure Observation

[0134] Fraction of Microstructure

[0135] A test piece for a scanning electron microscope (SEM) was taken from the hot rolled steel sheet, a sheet thickness cross-section parallel to the rolling direction was polished and, thereafter, the microstructure was allowed to appear with a corrosive liquid (3% nital solution). Photographs were taken in three fields of view of each of the position at one-quarter of the sheet thickness and the position at one-half of the sheet thickness (center position of the sheet thickness) with a scanning electron microscope (SEM) at the magnification of 3,000 times, and the area fraction of each phase was quantified on the basis of an image treatment.

[0136] Lath Interval of Laths of Bainite Phase

[0137] A test piece having size: 10 mm×15 mm was taken from the hot rolled steel sheet, thin film samples for transmission electron microscope (TEM) observation of the position at one-quarter of the sheet thickness and the position at one-half of the sheet thickness (center position of the sheet thickness) were produced, and photographs were taken in ten fields of view of each position with TEM at the magnification of 30,000 times. Five straight lines at intervals of 10 mm were drawn at right angles to long axes of at least three laths which were shown in each photograph having a size of 120 mm×80 mm and which were successively arranged side by side. The length of each line segment between the intersection points of the straight line and the lath boundary was measured and the average value of the resulting lengths of the segments was specified to be the average lath interval.

[0138] Long Axis Length of Lath of Bainite Phase

[0139] A test piece for a scanning electron microscope (SEM) was taken from the hot rolled steel sheet, a sheet thickness cross-section parallel to the rolling direction was polished and, thereafter, the microstructure was allowed to appear with a corrosive liquid (3% nital solution). Photographs were taken in five fields of view of each of the position at one-quarter of the sheet thickness and the position at one-half of the sheet thickness (center position of the sheet thickness) with a scanning electron microscope (SEM) at the magnification of 10,000 times. The lengths of long axes of at least 10 laths which were shown in each photograph, where at least three laths were successively arranged side by side, were measured and the average value of the resulting lath long axis lengths was specified to be the average lath long axis length.

(ii) Tensile Test

[0140] JIS No. 5 test pieces (GL: 50 mm) were taken from the hot rolled steel sheet in such a way that the tensile direction and the rolling direction form a right angle. A tensile test was performed in conformity with JIS Z 2241 (2011) and the yield strength (yield point) YP, the tensile strength (TS), and the total elongation El were determined.

(iii) Charpy Impact Test

[0141] A subsize test piece (V-notch) having a thickness of 5 mm was taken from the hot rolled steel sheet in such a way that the longitudinal direction of the test piece and the rolling direction form a right angle. A Charpy impact test was performed in conformity with JIS Z 2242, the Charpy impact value (vE_{-50}) at a temperature of −50° C. was measured, and the toughness was evaluated. Here, the hot rolled steel sheet having a sheet thickness of more than 5 mm was subjected to double-side polishing to produce a test piece having a sheet thickness of 5 mm. As for the hot rolled steel sheet having a sheet thickness of 5 mm or less, a test piece having the original sheet thickness was produced. Then, the test pieces were subjected to the charpy impact test. In the case where the measured vE_{-50} value was 40 J or more, the toughness was evaluated as good.

[0142] The obtained results are shown in Table 3 and Table 4.

TABLE 1

	Chemical composition (percent by mass) Remainder: Fe and incidental impurities										
Steel	C	Si	Mn	P	S	Al	N	Ti	V	Others	Remarks
A1	0.06	0.3	3.3	0.017	0.0017	0.073	0.0038	0.15	0.20	—	Invention steel
B1	0.15	0.7	2.0	0.037	0.0032	0.036	0.0026	0.12	0.20	—	Invention steel
C1	0.21	0.8	2.2	0.026	0.0006	0.042	0.0033	0.10	0.15	—	Comparative steel
D1	0.14	1.3	2.0	0.005	0.0009	0.043	0.0042	0.11	0.30	—	Comparative steel
E1	0.15	0.2	2.3	0.026	0.0012	0.022	0.0031	0.12	0.15	—	Invention steel
F1	0.14	0.5	3.8	0.018	0.0006	0.038	0.0039	0.09	0.25	—	Comparative steel
G1	0.04	0.7	2.0	0.021	0.0028	0.031	0.0025	0.03	0.20	—	Comparative steel
H1	0.04	0.9	1.6	0.022	0.0015	0.028	0.0037	0.23	0.11	—	Comparative steel
I1	0.13	0.6	1.6	0.016	0.0010	0.010	0.0028	0.17	0.05	—	Comparative steel
J1	0.15	0.8	1.8	0.025	0.0010	0.047	0.0029	0.06	0.25	—	Invention steel
K1	0.15	0.3	3.0	0.027	0.0008	0.067	0.0074	0.08	0.20	—	Invention steel
L1	0.12	0.8	1.3	0.027	0.0021	0.019	0.0039	0.18	0.11	—	Invention steel
M1	0.18	0.7	1.7	0.016	0.0009	0.055	0.0047	0.09	0.20	—	Invention steel
N1	0.12	0.4	1.7	0.004	0.0009	0.037	0.0055	0.08	0.15	Nb: 0.02	Invention steel
P1	0.14	0.3	1.8	0.030	0.0008	0.037	0.0070	0.12	0.20	Ni: 0.1, Cr: 0.1	Invention steel
Q1	0.16	0.7	2.1	0.020	0.0011	0.047	0.0041	0.15	0.15	Mo: 0.15	Invention steel
R1	0.15	0.5	1.9	0.035	0.0055	0.005	0.0034	0.11	0.22	B: 0.0005	Invention steel
S1	0.16	0.9	2.4	0.029	0.0016	0.093	0.0033	0.11	0.30	Ca: 0.005	Invention steel
T1	0.15	0.7	2.3	0.017	0.0045	0.031	0.0039	0.11	0.15	REM: 0.005	Invention steel
U1	0.13	0.6	2.2	0.022	0.0035	0.027	0.0037	0.13	0.18	Cu: 0.1	Invention steel

TABLE 2

		Hot rolling condition							
Hot rolled steel sheet No.	Steel	Slab heating temperature (° C.)	Finish rolling accumulated rolling reduction at 1000° Cor lower (%)	Finishing temperature (° C.)	Cooling start time (s)*	Average cooling rate (° C./s)	Coiling temperature (° C.)	Sheet thickness (mm)	Remarks
1	A1	1220	80	920	1	40	360	4	Invention example
1'		1220	80	910	1	40	360	4	Invention example
2		1220	80	910	1	40	470	4	Comparative example
3		1220	80	800	1	40	430	4	Comparative example
4	B1	1240	75	910	1.5	35	410	6	Invention example
5		1220	75	850	1.5	35	380	6	Invention example
6	C1	1220	55	900	3	25	390	12	Comparative example
7	D1	1240	75	880	1.5	35	350	6	Comparative example
8	E1	1220	55	950	2.5	25	370	10	Comparative example
9		1220	55	920	2.5	25	350	10	Invention example
10	F1	1220	55	840	3	25	380	12	Comparative example
11	G1	1220	60	870	2	30	320	8	Comparative example
12	H1	1240	50	910	3.5	20	430	14	Comparative example
13	I1	1220	75	880	1.5	35	380	6	Comparative example
14	J1	1220	45	910	3.5	20	400	14	Comparative example
15		1220	50	880	3.5	20	310	14	Invention example
16	K1	1240	75	900	1.5	10	370	6	Comparative example
17		1220	75	920	1.5	30	350	6	Invention example
18	L1	1280	80	890	1	35	380	4	Invention example
19		1170	80	850	1	40	430	4	Comparative example
20	M1	1260	60	900	2	30	280	8	Comparative example
21		1220	60	900	2	30	350	8	Invention example
22	N1	1220	55	920	3	25	330	12	Invention example
23	P1	1200	60	840	2	30	410	8	Invention example
24	Q1	1280	80	910	1	40	380	4	Invention example
25	R1	1220	80	880	1	35	350	4	Invention example
26	S1	1220	75	840	1.5	35	360	6	Invention example
27	T1	1220	75	910	1.5	35	390	6	Invention example
28	U1	1220	75	870	1.5	45	370	6	Invention example

*time from completion of finish rolling to start of forced cooling

TABLE 3

		Microstructure of hot rolled steel sheet**								
		B area fraction (%)		F + M + γarea fraction (%)		B average lath interval (nm)		B lath average long axis length (μm)		
Hot rolled steel sheet No.	Steel	¼ of sheet thickness	½ of sheet thickness	¼ of sheet thickness	½ of sheet thickness	¼ of sheet thickness	½ of sheet thickness	¼ of sheet thickness	½ of sheet thickness	Remarks
1	A1	88	90	12	10	260	290	2.9	3.5	Invention example
1'		89	91	11	9	270	300	3.0	3.7	Invention example
2		83	84	17	16	290	320	2.8	3.4	Comparative example
3		82	83	18	17	280	310	2.2	2.5	Comparative example
4	B1	86	88	14	12	340	370	3.2	3.9	Invention example
5		87	89	13	11	330	350	2.8	3.1	Invention example
6	C1	87	90	13	10	380	400	4.6	4.9	Comparative example
7	D1	88	91	12	9	350	370	3.4	3.8	Comparative example
8	E1	88	90	12	10	330	360	5.2	5.8	Comparative example
9		88	90	12	10	320	350	4.5	4.9	Invention example
10	F1	87	91	13	9	360	380	4.2	4.6	Comparative example
11	G1	89	92	11	8	350	380	5.3	6.1	Comparative example
12	H1	86	88	14	12	520	560	4.2	4.7	Comparative example
13	I1	87	91	13	9	370	390	3.9	4.8	Comparative example
14	J1	87	90	13	10	420	440	5.7	6.5	Comparative example
15		90	92	10	8	380	390	4.6	4.9	Invention example
16	K1	81	84	19	16	410	440	3.3	3.8	Comparative example
17		88	92	12	8	280	330	3.5	3.9	Invention example
18	L1	87	88	13	12	370	380	2.8	3.5	Invention example
19		86	88	14	12	370	390	2.6	3.1	Comparative example
20	M1	82	85	18	15	310	350	4.1	4.8	Comparative example
21		88	90	12	10	340	370	4.1	4.7	Invention example
22	N1	89	91	11	9	370	390	3.4	4.1	Invention example

TABLE 3-continued

Hot rolled steel sheet No.	Steel	Microstructure of hot rolled steel sheet** B area fraction (%) ¼ of sheet thickness	½ of sheet thickness	F + M + γarea fraction (%) ¼ of sheet thickness	½ of sheet thickness	B average lath interval (nm) ¼ of sheet thickness	½ of sheet thickness	B lath average long axis length (μm) ¼ of sheet thickness	½ of sheet thickness	Remarks
23	P1	86	89	14	11	310	350	3.4	3.9	Invention example
24	Q1	87	88	13	12	300	340	3.0	3.5	Invention example
25	R1	88	90	12	10	290	330	2.8	3.2	Invention example
26	S1	88	91	12	9	290	320	2.5	2.9	Invention example
27	T1	87	90	13	10	340	380	3.4	3.6	Invention example
28	U1	91	93	9	7	320	350	2.9	3.3	Invention example

**B: bainite phase, F: ferrite phase, M: martensite phase, γ: retained austenite phase

TABLE 4

Hot rolled steel sheet No.	Steel	Mechanical characteristics of hot rolled steel sheet Yield stress YP (Mpa)	Tensile strength TS (Mpa)	Total elongation El (%)	vE_{-50} (J)	Remarks
1	A1	961	1117	12.8	67	Invention example
1'		965	1119	11.8	62	Invention example
2		809	982	12.9	28	Comparative example
3		820	1012	11.7	31	Comparative example
4	B1	829	983	15.0	46	Invention example
5		877	1028	14.8	53	Invention example
6	C1	842	990	17.3	31	Comparative example
7	D1	999	1157	13.5	36	Comparative example
8	E1	846	988	17.1	28	Comparative example
9		879	1018	16.9	47	Invention example
10	F1	915	1072	16.0	27	Comparative example
11	G1	847	970	17.6	29	Comparative example
12	H1	894	1069	15.7	15	Comparative example
13	I1	862	1011	15.0	30	Comparative example
14	J1	786	928	18.9	19	Comparative example
15		932	1063	17.8	47	Invention example
16	K1	804	993	13.2	18	Comparative example
17		883	1023	15.3	68	Invention example
18	L1	899	1053	13.3	45	Invention example
19		819	978	13.6	34	Comparative example
20	M1	920	1122	12.5	23	Comparative example
21		878	1017	16.2	48	Invention example
22	N1	883	1014	17.8	60	Invention example
23	P1	836	992	15.7	43	Invention example
24	Q1	942	1104	12.6	52	Invention example
25	R1	942	1091	13.3	72	Invention example
26	S1	967	1124	13.7	69	Invention example
27	T1	844	993	15.2	44	Invention example
28	U1	923	1078	14.2	50	Invention example

[0143] The hot rolled steel sheets of Invention examples are hot rolled steel sheets having predetermined strength (e.g., TS: 980 MPa or more) and excellent toughness (e.g., vE_{-50} value: 40 J or more) in combination. Also, the hot rolled steel sheets of Invention examples have predetermined strength and excellent toughness at each of the position at ¼ of sheet thickness and the position at ½ of sheet thickness (sheet thickness center position) and, therefore, are hot rolled steel sheets having good characteristics in the entire region in the sheet thickness direction. On the other hand, the hot rolled steel sheets of Comparative examples out of the preferable scope of the present invention are unable to obtained predetermined strength or are unable to obtained sufficient toughness.

Second Embodiment

Hole Expansion Workability

[0144] To begin with, reasons for the limitation of the composition of the hot rolled steel sheet according to an embodiment of the present invention will be described. In this regard, the term "%" representing the content of each component element refers to "percent by mass" unless otherwise specified.

[0145] C: more than 0.1% and 0.2% or less

[0146] C is a beneficial element in an embodiment of the present invention having a function of facilitating formation of bainite and enhancing strength of the steel. In order to obtain such effects, it is advantageous that the C content be more than 0.1%. On the other hand, C bonds to Fe to form cementite, so that if the C content is excessive, the number of cementite grains is increased, the distances between the cementite grains serving as starting points of voids are reduced, the local ductility is degraded, and the hole expansion workability is degraded. Also, if the C content is excessive and, e.g., is more than 0.2%, the weldability is degraded. Consequently, C may be limited to within the range of more than 0.1% and 0.2% or less. In this regard, 0.12% to 0.17% is preferable.

[0147] Si: 1.0% or less

[0148] Si is an element which contributes to enhancement of strength of the steel through solid solution and which has a function of suppressing generation of coarse cementite and, therefore, is a beneficial element in an embodiment of the present invention. In particular, Si increases the intervals between cementite grains serving as starting points of voids through the function of suppressing generation of coarse cementite and, thereby, contributes to improvement of the local ductility and the hole expansion workability. In order to obtain such effects, the content is desirably 0.1% or more. On the other hand, if the content is more than 1.0%, the surface quality of the steel sheet is degraded significantly, and degradation in the chemical conversion treatability and the corrosion resistance may be caused. Therefore, Si may be limited to 1.0% or less. In this regard, 0.5% to 0.9% is preferable.

[0149] Mn: 1.5% to 2.5%

[0150] Mn is an element which contributes to enhancement of strength of the steel through solid solution and, in addition, which facilitates formation of a bainite phase through improvement of the hardenability. In order to obtain such effects, it is advantageous that the Mn content be 1.5% or more. On the other hand, if the Mn content is more than 2.5%, center segregation becomes significant, appearances of punched surface of the steel sheet are degraded, and the hole expansion workability may be degraded. Consequently, the amount of Mn may be specified to be within the range of 1.5% to 2.5%. In this regard, the range of 1.7% to 2.2% is preferable.

[0151] P: 0.05% or less

[0152] P contributes to enhancement of strength of the steel through solid solution but segregates at grain boundaries, in particular prior-austenite grain boundaries, to cause degradation in low-temperature toughness and workability. Consequently, it is preferable that P be minimized, although the content up to 0.05% can be allowable. Therefore, P may be specified to be 0.05% or less. In this regard, 0.03% or less is preferable, and 0.02% or less is further preferable.

[0153] S: 0.005% or less

[0154] S forms coarse sulfides by bonding to Ti and Mn and degrades the workability. Consequently, it is preferable that S be minimized, although the content up to 0.005% can be allowable. Therefore, S may be limited to 0.005% or less. In this regard, 0.003% or less is preferable, and 0.001% or less is further preferable.

[0155] Al: 0.10% or less

[0156] Al is an element which functions as a deoxidizing agent and which is effective in improving cleanliness of the steel. In order to obtain such effects, the content is desirably 0.005% or more. On the other hand, if the content is excessive and is, e.g., more than 0.10%, increases in oxide inclusions are caused, an occurrence of flaw is caused and, in addition, the workability of the steel sheet is degraded. Therefore, Al may be limited to 0.10% or less. In this regard, 0.01% to 0.05% is preferable.

[0157] N: 0.007% or less

[0158] N precipitates as nitrides by bonding to nitride-forming elements and contributes to making crystal grains fine. However, N bonds to Ti at a high temperature to form coarse nitrides easily and serves as a starting point of a void during hole expansion working easily. Consequently, N is preferably minimized in an embodiment of the present invention, although up to 0.007% can be allowable. Therefore, N may be limited to 0.007% or less. In this regard, 0.006% or less is preferable, and 0.005% or less is further preferable.

[0159] Ti: 0.07% to 0.2%

[0160] Ti contributes to enhancement of strength of the steel through formation of carbonitrides to make crystal grains fine and through precipitation strengthening. Also, Ti forms many fine (Ti,V)C clusters at a temperature range of about 300° C. to 500° C. (coiling temperature), has a function of reducing the amount of cementite in the steel, and is a beneficial element in and embodiment of the present invention. In order to exert such effects, it is advantageous that the content be 0.07% or more. On the other hand, if the content is excessive and is more than 0.2%, the above-described effects are saturated, increases in coarse precipitates are caused, and degradation in the hole expansion workability may be caused. Also, Ti facilitates formation of a ferrite phase, so that a predetermined microstructure cannot be obtained and the hole expansion workability is degraded. Therefore, Ti may be limited to within the range of 0.07% to 0.2%. In this regard, 0.1% to 0.15% is preferable.

[0161] V: more than 0.1% and 0.3% or less

[0162] V is an element which contributes to enhancement of strength of the steel through formation of carbonitrides to make crystal grains fine and through precipitation strengthening and which also contributes to formation and making fine of bainite phase through an improvement of the hardenability. In addition, V forms many fine (Ti,V)C clusters in a temperature range of about 300° C. to 500° C. (coiling temperature), has a function of reducing the amount of cementite in the steel, and is a beneficial element in an embodiment of the present invention. In order to exert such effects, it is advantageous that the content be more than 0.1%. On the other hand, if the content is excessive and is more than 0.3%, the ductility may be degraded and, in addition, an increase in the cost is caused. Therefore, V may be limited to within the range of more than 0.1% and 0.3% or less. In this regard, 0.13% to 0.27% is preferable and 0.15% to 0.25% is further preferable.

[0163] The above-described components are the basic components. In the present invention, besides the basic composition, as necessary, at least one selected from Nb: 0.005% to 0.1%, B: 0.0002% to 0.002%, Cu: 0.005% to 0.3%, Ni: 0.005% to 0.3%, Cr: 0.005% to 0.3%, and Mo: 0.005% to 0.3% and/or one or two selected from Ca: 0.0003% to 0.01% and REM: 0.0003% to 0.01% may be further contained as selective elements.

[0164] At least one selected from Nb: 0.005% to 0.1%, B: 0.0002% to 0.002%, Cu: 0.005% to 0.3%, Ni: 0.005% to 0.3%, Cr: 0.005% to 0.3%, and Mo: 0.005% to 0.3%

[0165] Each of Nb, B, Cu, Ni, Cr, and Mo is an element which contributes to enhancement of strength of the steel and at least one may be selected and contained, as necessary.

[0166] Nb is an element which contributes to enhancement of strength of the steel through formation of carbonitrides. In order to exert such an effect, it is preferable that the content be 0.005% or more. On the other hand, if the content is more than 0.1%, deformation resistance increases, a rolling force of hot rolling increases, a load to a rolling mill becomes too large, rolling operation in itself becomes difficult and, in addition, coarse precipitates are formed, so that degradation in the workability is caused. Consequently, in the case where Nb is contained, Nb may be limited to within the range of preferably 0.005% to 0.1%. In this regard, 0.01% to 0.05% is more preferable and 0.02% to 0.04% is further preferable.

[0167] B is an element having functions of segregating at austenite grain boundaries, suppressing formation and growth of ferrite, improving hardenability, contributing to formation and making fine of bainite phase, and enhancing strength of the steel. In order to exert such effects, it is preferable that the content be 0.0002% or more. However, if the content is more than 0.002%, the workability is degraded significantly. Therefore, in the case where B is contained, B may be limited to within the range of preferably 0.0002% to 0.002%. In this regard, 0.0005% to 0.0015% is more preferable.

[0168] Cu is an element having functions of enhancing strength of the steel through solid solution and improving hardenability. In particular, Cu lowers the bainite transformation temperature and contributes to making bainite phase fine. In order to obtain such effects, it is preferable that the content be 0.005% or more, although if the content is more than 0.3%, degradation in the surface quality is caused. Therefore, in the case where Cu is contained, Cu may be limited to within the range of preferably 0.005% to 0.3%. In this regard, 0.01% to 0.2% is more preferable.

[0169] Ni is an element having functions of enhancing strength of the steel through solid solution, improving hardenability, and facilitating formation of bainite phase. In order to obtain such effects, it is preferable that the content be 0.005% or more. However, if the content is more than 0.3%, a martensite phase is generated easily, and the hole expansion workability is degraded significantly. Therefore, in the case where Ni is contained, Ni may be limited to within the range of preferably 0.005% to 0.3%. In this regard, 0.01% to 0.2% is more preferable.

[0170] Cr is an element which forms carbides and contributes to enhancement of strength of the steel. In order to exert such effects, it is preferable that the content be 0.005% or more. On the other hand, if the content is excessive and is more than 0.3%, the corrosion resistance of the steel is degraded. Therefore, in the case where Cr is contained, Cr is limited to within the range of preferably 0.005% to 0.3%. In this regard, 0.01% to 0.2% is more preferable.

[0171] Mo is an element having functions of improving hardenability, facilitating formation of bainite phase, and enhancing strength of the steel. In order to obtain such effects, it is preferable that the content be 0.005% or more. However, if the content is more than 0.3%, a martensite phase may be generated easily, and the hole expansion workability is degraded significantly. Therefore, in the case where Mo is contained, Mo may be limited to within the range of preferably 0.005% to 0.3%. In this regard, 0.01% to 0.2% is more preferable.

[0172] One or two selected from Ca: 0.0003% to 0.01% and REM: 0.0003% to 0.01%

[0173] Each of Ca and REM is an element which contributes to improvement of the hole expansion workability through shape control of inclusions and one or two may be selected and contained, as necessary.

[0174] Ca is an element which controls the shape of inclusions and which contributes to improvement of the hole expansion workability effectively. In order to exert such effects, it is advantageous that the content be 0.0003% or more. On the other hand, if the content is excessive and is more than 0.01%, the amount of inclusions increases and many surface defects are caused. Therefore, in the case where Ca is contained, Ca is limited to within the range of preferably 0.0003% to 0.01%.

[0175] As with Ca, REM is an element which controls the shape of sulfide inclusions to improve adverse influences of sulfide inclusions on the hole expansion workability and, thereby, contributes to improvement of the hole expansion workability. In order to exert such effects, it is advantageous that the content be 0.0003% or more. On the other hand, if the content is excessive and is more than 0.01%, the amount of inclusions increases, the cleanliness of the steel is degraded, and the hole expansion workability may be degraded. Therefore, in the case where REM is contained, REM may be limited to within the range of preferably 0.0003% to 0.01%.

[0176] The balance other than those described above is composed of Fe and incidental impurities. In this regard, as for the incidental impurities, O (oxygen): 0.005% or less, W: 0.1% or less, Ta: 0.1% or less, Co: 0.1% or less, Sb: 0.1% or less, Sn: 0.1% or less, Zr: 0.1% or less, and the like can be allowable.

[0177] Next, reasons for the limitation of the microstructure of the hot rolled steel sheet according to an aspect of the present invention will be described.

[0178] In the hot rolled steel sheet according to an embodiment of the present invention, the primary phase is specified to be a bainite phase. Here, the term "primary phase" refers to a phase having an area fraction of 90% or more. If a phase other than the bainite phase is specified to be the primary phase, predetermined high strength and good hole expansion workability cannot be obtained stably. Consequently, the primary phase may be specified to be bainite phase having an area fraction of 90% or more. In this regard, 92% or more is preferable, and 95% or more is more preferable.

[0179] The remainder other than the bainite phase serving as the primary phase may be at least one selected from martensite phase, austenite phase (retained austenite phase), and ferrite phase. The phases of the reminder other than the primary phase are specified to be 10% or less in total (including 0%) on an area fraction basis. If the phases of the reminder other than the bainite phase are more than 10%, predetermined high strength and good hole expansion workability may not be obtained stably. In particular, if the martensite phase increases, predetermined good hole expansion workability cannot be obtained stably.

[0180] The hot rolled steel sheet according to an embodiment of the present invention has the above-described microstructure, where the microstructure shows that cementite is dispersed in the microstructure. Cementite is present while being dispersed mainly in the bainite phase, although may be present in the phases other than bainite or at the phase boundaries. In the hot rolled steel sheet according to an embodiment of the present invention, cementite dispersed in the microstructure is specified to be 0.8% or less on a percent by mass basis and the average grain size is specified to be 150 nm or less.

[0181] In the case where a large amount of cementite is dispersed in the microstructure, where the proportion is more than 0.8% on a percent by mass basis, the number of dispersed cementite grains increases, voids started from cementite are connected easily during working, the local ductility is degraded, and the hole expansion workability may be degraded. Consequently, cementite may be limited to 0.8% or less on a percent by mass basis. In this regard, 0.6% or less is preferable, and 0.5% or less is more preferable.

[0182] Also, in the case where cementite is coarsened and the average grain size is more than 150 nm, coarse voids started from cementite are generated easily during working, and the hole expansion workability may be degraded. Consequently, the average grain size of cementite may be limited to 150 nm or less. In this regard, 130 nm or less is preferable, and 110 nm or less is further preferable.

[0183] Next, a preferable method for manufacturing the hot rolled steel sheet according to an aspect of the present invention will be described.

[0184] In an aspect of the present invention, a hot rolled steel sheet is produced through the steps of heating a steel, applying hot rolling having rough rolling and finish rolling, performing cooling composed of two stages of first stage cooling and second stage cooling, and performing coiling.

[0185] The method for manufacturing a steel serving as a starting material is not necessarily particularly limited, and any common manufacturing method can be applied, wherein a molten steel having the above-described composition is refined by a common refining method, e.g., a converter, and a steel, e.g., a slab, is produced by a common casting method, e.g., a continuous casting method. In this regard, an ingot-making and blooming method may be employed without problem.

[0186] Meanwhile, in an embodiment of the present invention, electro-magnetic stirrer (EMS), intentional bulging soft reduction casting (IBSR), and the like can be applied to reduce component segregation of the steel during continuous casting. Equiaxial crystals are formed in the sheet thickness center portion by applying an electro-magnetic stirrer treatment, so that segregation can be reduced. Also, in the case where the intentional bulging soft reduction casting is applied, segregation in the sheet thickness center portion can be reduced by preventing flowing of the molten steel in an unsolidified portion of the continuous casting slab. The elongation and the hole expansion workability in tensile characteristics described below can be brought to a more excellent level by applying at least one of these segregation reduction treatments.

[0187] Initially, the resulting steel may be heated to heating temperature: 1,200° C. or higher.

[0188] Heating temperature: 1,200° C. or higher

[0189] Carbonitride-forming elements, e.g., Ti, are contained in the steel employed in an embodiment of the present invention. Most of these carbonitride-forming elements are present as coarse carbonitrides (precipitates). In this regard, the presence of coarse carbonitride-forming elements, e.g., Ti, which remain coarse precipitates, causes reduction in the amount of fine precipitates, which contribute to solute strengthening. Consequently, the steel sheet strength is reduced. In order to allow these coarse precipitates to form solid solutions before hot rolling, the heating temperature may be limited to 1,200° C. or higher. In this regard, 1,220° C. to 1,350° C. is preferable.

[0190] Subsequently, the heated steel may be subjected to hot rolling composed of rough rolling and finish rolling.

[0191] The condition of the rough rolling is not specifically limited insofar as predetermined sheet bar dimensions are ensured. Following the rough rolling, the finish rolling with finishing temperature: 850° C. to 950° C. may be applied. In this regard, as a matter of course, descaling is performed before the finish rolling or between finish rolling stands during rolling.

[0192] Finishing temperature: 850° C. to 950° C.

[0193] If the finishing temperature is lower than 850° C., finish rolling is rolling in two-phase region of ferrite+austenite, so that a deformation microstructure remains after rolling and the hole expansion workability may be degraded. On the other hand, if the finishing temperature is high and is higher than 950° C., austenite grains grow, and a bainite phase of the hot rolled sheet obtained after cooling is coarsened. Consequently, the hole expansion workability may be degraded. Therefore, the finishing temperature may be limited to within the range of 850° C. to 950° C. In this regard, 870° C. to 930° C. is preferable. Here, the term “finishing temperature” refers to the surface temperature.

[0194] After the finish rolling is completed, cooling composed of two stages of first stage cooling and second stage cooling may be applied.

[0195] In the first stage cooling, cooling may be started within 1.5 s of, preferably just after, completion of the finish rolling, and cooling to a first stage cooling stop temperature of 500° C. to 600° C. may be performed at an average cooling rate of 20° C./s to 80° C./s.

[0196] If the time until cooling of the first stage cooling is started is long and is more than 1.5 s, austenite grains become coarse and a bainite phase may be coarsened. Also, if austenite grains become coarse, the hardenability of the steel sheet increases and a martensite phase is generated easily, so that predetermined excellent hole expansion workability cannot be obtained. Therefore, the cooling start time of the first stage cooling may be limited to within 1.5 s of completion of the finish rolling.

[0197] Meanwhile, if the average cooling rate of the first stage cooling is less than 20° C./s and, therefore, cooling becomes slow, formation of ferrite or coarse bainite is facilitated, and predetermined high strength or hole expansion workability may not be obtained. On the other hand, if quenching is performed at more than 80° C./s, martensite is generated easily to become hard, and the hole expansion workability may be degraded. Consequently, the average cooling rate of the first stage cooling may be limited to within the range of 20° C./s to 80° C./s. In this regard, 25° C./s to 60° C./s is preferable.

[0198] Meanwhile, if the first stage cooling stop temperature is lower than 500° C., a transition boiling region is reached, variations in steel sheet temperature increase, the microstructure becomes heterogeneous, and predetermined excellent hole expansion workability may not be obtained. On the other hand, if the first stage cooling stop temperature is a high temperature higher than 600° C., ferrite transformation is facilitated, and predetermined high strength may not be obtained. Consequently, the first stage cooling stop temperature may be limited to 500° C. to 600° C. In this regard, 520° C. to 580° C. is preferable.

[0199] The second stage cooling may be started just after or within 3 s of, preferably just after, completion of the first stage cooling, and cooling to a second stage cooling stop temperature of 330° C. to 470° C. may be performed at an average cooling rate of 90° C./s or more.

[0200] If the time until cooling of the second stage cooling is started is long and is more than 3 s, ferrite transformation is started and predetermined high strength may not be obtained. Therefore, the cooling start time of the second stage cooling may be limited to within 3 s of completion of the first stage cooling.

[0201] Meanwhile, if the average cooling rate of the second stage cooling is less than 90° C./s, generated bainite is coarsened, and predetermined hole expansion workability may not be obtained. Consequently, the average cooling rate of the second stage cooling may be limited to 90° C./s or more. In this regard, the upper limit of the average cooling rate of the second stage cooling is not specifically limited, although the upper limit may be about 250° C./s in association with the sheet thickness of a sheet to be cooled and the capability of cooling equipment. In this regard, 100° C./s to 200° C./s is preferable.

[0202] Meanwhile, if the second stage cooling stop temperature is lower than 330° C., hard martensite phase and retained austenite phase are formed in the steel sheet microstructure, a predetermined microstructure may not be obtained, and the hole expansion workability may be degraded. On the other hand, if the second stage cooling stop temperature is a high temperature higher than 470° C., a ferrite phase and a martensite phase increase in the steel sheet microstructure, predetermined microstructure cannot be obtained, and the hole expansion workability may be degraded significantly. Consequently, the second stage cooling stop temperature may be limited to 330° C. to 470° C. In this regard, 350° C. to 450° C. is preferable.

[0203] After cooling to the second stage cooling stop temperature is performed, hot rolled steel sheet (steel strip in coil) may be produced by performing coiling into the shape of a coil, where a coiling temperature is specified to be the second stage cooling stop temperature.

[0204] In this regard, the above-described temperature refers to a steel sheet surface temperature.

[0205] In this regard, after the coiling, the hot rolled steel sheet may further be subjected to temper rolling following the common method. Also, the resulting hot rolled steel sheet may be subjected to pickling to remove scale formed on the surface. Alternatively, after the pickling, a galvanization process, e.g., hot dip galvanizing or electrogalvanizing, and a chemical conversion treatment may further be applied.

Example 2

[0206] A molten steel having the composition shown in Table 5 was refined in a converter, and a slab (steel) was produced by a continuous casting method. In the continuous casting, those other than Hot rolled steel sheet No. 1' of Steel A2 in Tables 5 to 7B described later were subjected to electromagnetic stirrer (EMS) for the purpose of segregation reduction treatment of the components. Subsequently, these steels were heated under the conditions shown in Tables 6A and 6B, and were subjected to hot rolling composed of rough rolling and finish rolling under the conditions shown in Tables 6A and 6B. After the finish rolling was completed, cooling was performed under the conditions shown in Tables 6A and 6B, and coiling was performed at coiling temperatures shown in Tables 6A and 6B, so that hot rolled steel sheets having sheet thicknesses shown in Tables 6A and 6B were produced. Cooling of some hot rolled steel sheets were specified to be single stage cooling.

[0207] Test pieces were taken from the resulting hot rolled steel sheets, and microstructure observation, a tensile test, and a hole expanding test were performed. The testing methods were as described below.

(1) Microstructure Observation

[0208] A test piece for a microstructure observation was taken from the resulting hot rolled steel sheet, a sheet thickness cross-section parallel to the rolling direction was polished, and the microstructure was allowed to appear with a corrosive liquid (3% nital solution). The microstructure of the position at one-quarter of the sheet thickness was observed with a scanning electron microscope (SEM), and photographs of the microstructure were taken in three fields of view (magnification: 3,000 times). The microstructure fraction (area fraction) of each phase was calculated on the basis of identification of the microstructure and image analysis.

[0209] A test piece (size: 10 mm×15 mm) for replica was taken from the position at one-quarter of the sheet thickness of the resulting hot rolled steel sheet, a replica film was produced by a two-stage replica method, and cementite was taken. The resulting cementite was observed with a transmission electron microscope (TEM), and photographs were taken in five fields of view (magnification: 50,000 times). The grain size of each cementite was determined and the average grain size of cementite of the steel sheet concerned was determined by averaging. In this regard, in the case of cementite having an aspect ratio, the average value of the long axis length and the short axis length was specified to be the grain size of the cementite concerned.

[0210] A test piece (size: t×50×100 mm) for electrolytic residue extraction was taken from the resulting hot rolled steel sheet. The total thickness of the test piece was subjected to constant-current electrolysis in a 10 vol % AA electrolyte (10 vol % acetylacetone-1 mass % tetramethylammonium chloride methanol) at current density: 20 mA/cm^2. The resulting electrolyte was filtrated and the electrolytic residue remaining on the filter paper was analyzed with an inductively-coupled plasma spectrophotometric analyzer to measure the amount of Fe in the electrolytic residue. It was assumed that quantified Fe was entirely Fe_3C, and the amount of precipitated cementite was calculated on the basis of the following formula.

$$Fe_3C \text{ (percent by mass)}=(1.0716\times[\text{quantified Fe(g)}])/[\text{electrolyzed weight (g)}]\times 100$$

In this regard, the atomic weight of Fe was specified to be 55.85 (g/mol) and the atomic weight of C was specified to be 12.01 (g/mol). Meanwhile, the electrolyzed weight was determined by cleaning the test piece for electrolysis after the electrolysis, measuring the weight, and subtracting the resulting weight from the test piece weight before electrolysis.

(2) Tensile Test

[0211] JIS No. 5 test pieces (GL: 50 mm) were taken from the resulting hot rolled steel sheet in such a way that the tensile direction and the rolling direction forma right angle. A tensile test was performed in conformity with JIS Z 2241 and the yield strength (yield point) YP, the tensile strength TS, and the elongation El were determined.

(3) Hole Expanding Test

[0212] A test piece (size: t×100×100 mm) for hole expanding test was taken from the resulting hot rolled steel sheet. In conformity with The Japan Iron and Steel Federation Standards JFST 1001, a punched hole was punched in the center of the test piece with a 10 mmϕ punch, where clearance: 12.5% of sheet thickness. Thereafter, a 60° cone punch was inserted into the punched hole along the punching direction in such a way as to be pushed upward, and a hole diameter d mm at the point in time when a crack penetrated the sheet thickness was determined, and the hole expanding ratio k (%) defined by the following formula

$$\lambda(\%)=\{(d-10)/10\}\times 100$$

was calculated.

[0213] Also, a test piece (size: t×100×100 mm) for hole expanding test was taken from the resulting hot rolled steel sheet. A punched hole was punched in the center of the test piece with a 10 mmϕ punch, where clearance: 25.0% of sheet thickness. Thereafter, a 60° cone punch was inserted into the punched hole along the punching direction in such a way as to be pushed upward, and a hole diameter d mm at the point in time when a crack penetrated the sheet thickness was determined, and the hole expanding ratio λ(%) was calculated by the above-described formula. In this regard, the clearance refers to the proportion (%) relative to the sheet thickness.

[0214] Then, the case where λ obtained by the hole expanding test performed with respect to the punched hole punched with a clearance of 12.5% was 60% or more and λ obtained by the hole expanding test performed with respect to the punched hole punched with a clearance of 25.0% was 40% or more was evaluated as good hole expansion workability.

[0215] The obtained results are shown in Tables 7A and 7B.

TABLE 5

Steel No.	Chemical component (percent by mass) C	Si	Mn	P	S	Al	N	Ti	V	Nb, B, Cu, Ni, Cr, Mo	REM, Ca	Remarks
A2	0.11	0.5	2.4	0.014	0.0018	0.055	0.0031	0.15	0.24	—	—	Adaptation example
B2	0.15	0.7	2.0	0.019	0.0014	0.087	0.0055	0.12	0.20	—	—	Adaptation example
C2	0.18	0.8	2.2	0.019	0.0008	0.025	0.0062	0.10	0.15	—	—	Adaptation example
D2	0.19	0.9	2.4	0.023	0.0010	0.079	0.0057	0.11	0.30	—	—	Adaptation example
E2	0.15	0.2	2.3	0.015	0.0008	0.019	0.0065	0.15	0.25	—	—	Adaptation example
F2	0.14	0.5	1.9	0.014	0.0039	0.037	0.0027	0.09	0.25	—	—	Adaptation example
G2	0.12	0.7	2.0	0.008	0.0026	0.034	0.0056	0.15	0.20	—	—	Adaptation example
H2	0.11	0.9	1.6	0.013	0.0015	0.075	0.0039	0.18	0.11	—	—	Adaptation example
I2	0.13	0.6	1.6	0.013	0.0004	0.013	0.0022	0.17	0.15	—	—	Adaptation example
J2	0.14	0.6	1.8	0.014	0.0021	0.043	0.0049	0.14	0.17	—	—	Adaptation example
K2	0.13	0.5	1.9	0.011	0.0013	0.030	0.0043	0.08	0.20	Nb: 0.02	—	Adaptation example
L2	0.16	0.8	2.3	0.045	0.0011	0.031	0.0028	0.09	0.11	B: 0.0005	—	Adaptation example
M2	0.11	0.7	2.4	0.012	0.0009	0.045	0.0032	0.12	0.15	Ni: 0.2, Cr: 0.2	—	Adaptation example
N2	0.12	0.4	1.7	0.008	0.0020	0.024	0.0048	0.08	0.15	Nb: 0.01, Mo: 0.2	—	Adaptation example
O2	0.11	0.1	2.2	0.007	0.0014	0.021	0.0010	0.10	0.12	B: 0.0007	—	Adaptation example
P2	0.14	0.3	1.8	0.018	0.0008	0.055	0.0053	0.12	0.20	—	Ca: 0.005	Adaptation example
Q2	0.16	0.7	2.1	0.004	0.0028	0.035	0.0018	0.15	0.15	—	REM: 0.005	Adaptation example
R2	0.15	0.5	1.9	0.025	0.0023	0.041	0.0029	0.11	0.22	Cu: 0.1	—	Adaptation example
S2	0.19	0.9	2.4	0.015	0.0027	0.031	0.0063	0.11	0.30	—	—	Adaptation example
T2	0.15	0.7	2.3	0.015	0.0019	0.052	0.0049	0.11	0.15	B: 0.001	—	Adaptation example
U2	0.05	1.3	2.4	0.019	0.0021	0.041	0.0033	0.16	—	Nb: 04	—	Comparative example
V2	0.22	0.5	2.8	0.018	0.0014	0.029	0.0046	0.10	0.05	Nb: 0.02	—	Comparative example
W2	0.15	0.1	2.5	0.010	0.0090	0.035	0.0072	0.07	0.05	Cr: 0.2/Mo: 0.2	—	Comparative example
X2	0.12	0.3	2.1	0.037	0.0011	0.058	0.0052	0.09	0.11	—	—	Adaptation example
Y2	0.05	0.5	1.9	0.016	0.0031	0.017	0.0041	0.15	—	—	—	Comparative example
Z2	0.14	0.7	1.2	0.016	0.0020	0.028	0.0047	0.09	0.30	—	—	Comparative example
AA2	0.11	0.8	1.7	0.012	0.0016	0.020	0.0038	0.25	0.15	—	—	Comparative example
AB2	0.14	0.7	2.3	0.016	0.0014	0.034	0.0035	0.05	0.20	—	—	Comparative example

TABLE 6A

		Production condition							
				First stage cooling			Second stage cooling		
Steel sheet No.	Steel No.	Heating temperature (° C.)	Finishing temperature (° C.)	Cooling start time* (s)	Average cooling rate (° C./s)	Cooling stop temperature (° C.)	Cooling start time** (s)	Average cooling rate (° C./s)	Cooling stop temperature (° C.)
1	A2	1240	920	0.5	25	530	1.0	110	370
1'	A2	1240	920	0.6	25	520	1.0	110	370
2	A2	1230	910	0.5	30	560	2.5	150	420
3	A2	1210	900	1.5	35	540	3.0	100	310
4	B2	1230	910	0.5	45	560	3.0	100	410
5	B2	1240	920	0.0	25	540	1.5	160	370
6	B2	1240	890	1.0	30	560	2.5	100	440
7	C2	1220	910	0.5	25	570	2.0	140	360
8	C2	1260	910	0.0	20	560	0.0	95	430
9	D2	1250	930	0.5	35	550	3.0	100	370
10	D2	1240	910	1.0	30	570	2.5	95	440
11	E2	1230	900	1.5	45	540	2.5	120	380
12	E2	1250	920	0.0	25	550	1.5	110	430
13	F2	1270	910	0.5	25	540	1.5	110	490
14	F2	1260	890	1.0	25	540	1.5	100	380
15	G2	1220	890	1.0	25	540	1.5	130	380
16	G2	1250	930	0.5	30	540	2.0	100	430
17	H2	1270	910	0.0	25	570	2.0	120	350
18	H2	1250	920	0.5	30	570	2.5	100	380
19	H2	1230	900	1.0	10	560	0.0	95	420
20	I2	1210	920	1.0	30	540	2.0	95	370
21	I2	1210	910	0.5	25	530	1.0	10	440
22	J2	1270	920	0.5	30	540	2.0	90	380
23	J2	1260	910	1.0	30	560	2.5	120	440
24	K2	1250	920	0.5	25	550	1.5	120	360
25	K2	1250	900	0.0	25	550	1.5	100	410
26	L2	1220	900	0.5	25	540	1.5	110	360

TABLE 6A-continued

Steel sheet No.	Production condition Coiling temperature (° C.)	Sheet thickness (mm)	Remarks
1	370	2.9	Invention example
1'	370	2.9	Invention example
2	420	2.0	Invention example
3	310	3.6	Comparative example
4	410	3.6	Invention example
5	370	2.0	Invention example
6	440	3.6	Invention example
7	360	2.3	Invention example
8	430	4.0	Invention example
9	370	3.6	Invention example
10	440	4.0	Invention example
11	380	2.6	Invention example
12	430	2.9	Invention example
13	490	2.9	Comparative example
14	380	3.6	Invention example
15	380	2.3	Invention example
16	430	2.9	Invention example
17	350	2.6	Invention example
18	380	3.6	Invention example
19	420	4.0	Comparative example
20	370	4.0	Invention example
21	440	4.0	Comparative example
22	380	4.0	Invention example
23	440	2.6	Invention example
24	360	2.6	Invention example
25	410	3.6	Invention example
26	360	2.9	Invention example

*time from finish rolling completion

**time from first stage cooling completion

TABLE 6B

		Production condition								
				First stage cooling			Second stage cooling			
Steel sheet No.	Steel No.	Heating temperature (° C.)	Finishing temperature (° C.)	Cooling start time* (s)	Average cooling rate (° C./s)	Cooling stop temperature (° C.)	Cooling start time** (s)	Average cooling rate (° C./s)	Cooling stop temperature (° C.)
27	L2	1210	910	1.0	30	550	2.0	95	410
28	M2	1270	890	0.5	50	550	2.0	95	380
29	M2	1210	900	1.0	30	560	2.5	150	420
30	M2	1220	920	0.5	25	470	0.5	100	360
31	N2	1210	890	0.5	25	540	1.5	110	350
32	N2	1250	970	0.5	25	560	1.0	130	440
33	O2	1270	890	0.5	25	540	1.5	120	360
34	O2	1270	910	1.0	30	550	2.0	100	370
35	P2	1240	910	0.5	25	560	1.5	120	360
36	P2	1240	830	0.5	25	530	2.0	100	420
37	Q2	1220	910	1.0	30	540	2.0	100	380
38	Q2	1210	920	0.5	25	530	0.5	110	360
39	R2	1220	900	1.0	30	560	2.5	100	360
40	R2	1150	910	0.5	25	560	1.5	95	380
41	R2	1220	870	1.0	30	550	2.0	110	440
42	S2	1220	910	1.0	25	560	1.5	95	400
43	S2	1250	920	0.5	30	540	2.0	100	420
44	T2	1220	920	0.0	25	540	1.5	120	360
45	T2	1250	910	1.0	30	550	2.0	110	420
46	U2	1220	910	1.5	40	—	—	40	480
47	V2	1240	890	1.0	30	560	2.5	120	440
48	W2	1200	900	0.5	25	—	—	25	400
49	X2	1260	920	0.5	25	530	1.0	110	300
50	Y2	1250	880	1.0	30	540	2.5	100	420
51	Z2	1250	910	0.5	25	540	1.5	100	420
52	AA2	1220	920	0.5	25	540	1.0	110	400

TABLE 6B-continued

53	AB2	1250	910	1.0	30	540	2.0	110	420
54	C2	1250	920	3.0	30	550	1.5	100	400
55	I2	1250	890	0.5	30	540	5.0	100	380

Steel sheet No.	Production condition Coiling temperature (° C.)	Sheet thickness (mm)	Remarks
27	410	3.9	Invention example
28	380	3.9	Invention example
29	420	2.0	Invention example
30	360	3.6	Comparative example
31	350	3.2	Invention example
32	440	2.3	Comparative example
33	360	2.6	Invention example
34	370	3.6	Invention example
35	360	2.6	Invention example
36	420	3.6	Comparative example
37	380	3.6	Invention example
38	360	3.2	Invention example
39	360	3.6	Invention example
40	380	4.0	Comparative example
41	440	2.9	Invention example
42	400	4.0	Invention example
43	420	2.9	Invention example
44	360	2.6	Invention example
45	420	2.9	Invention example
46	480	3.6	Comparative example
47	440	2.6	Comparative example
48	400	4.0	Comparative example
49	300	3.2	Comparative example
50	420	3.6	Comparative example
51	420	3.6	Comparative example
52	400	3.2	Comparative example
53	420	2.9	Comparative example
54	400	3.2	Comparative example
55	380	3.2	Comparative example

*time from finish rolling completion

**time from first stage cooling completion

TABLE 7A

Steel sheet No.	Steel No.	Microstructure Type*	Microstructure Bainite phase area fraction (%)	Microstructure Cementite average grain size (nm)	Microstructure Amount of cementite (percent by mass)	Tensile characteristics Yield strength YP (MPa)	Tensile characteristics Tensile strength TS (MPa)	Tensile characteristics Elongation EI (%)
1	A2	B + M	94	101	0.51	954	1094	14.3
1'	A2	B + M	95	104	0.52	956	1097	13.4
2	A2	B + M	92	123	0.68	911	1069	16.6
3	A2	B + M	88	74	0.27	922	1124	12.6
4	B2	B + M	93	125	0.67	871	1018	16.9
5	B2	B	100	107	0.51	913	1038	14.2
6	B2	B + M	93	138	0.74	863	1003	16.7
7	C2	B + M	95	110	0.49	891	1017	14.9
8	C2	B + M	92	141	0.76	832	982	18.2
9	D2	B + M	94	92	0.44	966	1108	14.2
10	D2	B + M	91	123	0.72	905	1073	17.4
11	E2	B + M	94	89	0.53	957	1103	14.6
12	E2	B + M	92	111	0.73	914	1078	16.9
13	F2	B + M + F	88	173	0.99	779	927	19.8
14	F2	B + M	94	104	0.55	852	982	16.2
15	G2	B + M	95	102	0.47	950	1084	14.1
16	G2	B + M	92	134	0.75	890	1049	17.3
17	H2	B + M	95	111	0.46	966	1097	13.5
18	H2	B + M	94	125	0.58	939	1082	14.9
19	H2	B + M + F	85	143	0.74	892	1062	18.6
20	12	B + M	94	114	0.55	925	1061	14.7
21	12	B + F + P	79	142	0.89	872	1026	19.5
22	J2	B + M	94	116	0.58	894	1030	15.5
23	J2	B + M	91	143	0.69	844	1000	18.3

TABLE 7A-continued

24	K2	B + M	95	102	0.49	877	1001	15.2
25	K2	B + M	93	125	0.69	841	983	17.5
26	L2	B + M	95	116	0.51	909	1038	14.6

	Hole expansion workability Hole expanding ratio λ (%)		
Steel sheet No.	Clearance: 12.5%	Clearance: 25%	Remarks
1	75	59	Invention example
1'	65	48	Invention example
2	63	43	Invention example
3	45	28	Comparative example
4	62	46	Invention example
5	77	64	Invention example
6	64	42	Invention example
7	73	60	Invention example
8	65	44	Invention example
9	78	64	Invention example
10	63	41	Invention example
11	71	57	Invention example
12	64	48	Invention example
13	61	33	Comparative example
14	67	53	Invention example
15	67	53	Invention example
16	61	45	Invention example
17	71	58	Invention example
18	66	52	Invention example
19	48	32	Comparative example
20	72	58	Invention example
21	51	29	Comparative example
22	71	57	Invention example
23	63	47	Invention example
24	80	66	Invention example
25	64	45	Invention example
26	67	54	Invention example

*B: bainite, F: ferrite, P: pearlite, M: martensite, θ: cementite, γ: retained austenite

TABLE 7B

Steel sheet No.	Steel No.	Microstructure Type*	Bainite phase area fraction (%)	Cementite average grain size (nm)	Amount of cementite (percent by mass)	Tensile characteristics Yield strength YP (MPa)	Tensile strength TS (MPa)	Elongation EI (%)
27	L2	B + M + F	91	132	0.72	842	998	18.3
28	M2	B + M	94	119	0.58	997	1148	14.1
29	M2	B + M	95	137	0.71	993	1128	13.2
30	M2	B + M + F	87	110	0.50	984	1158	17.0
31	N2	B + M	95	105	0.49	879	999	14.7
32	N2	B + M	95	167	0.91	840	954	18.3
33	O2	B + M	95	117	0.58	865	987	15.3
34	O2	B + M	94	122	0.62	856	982	15.8
35	P2	B	100	102	0.51	896	1004	15.2
36	P2	B + M + F	82	129	0.75	845	982	17.3
37	Q2	B + M	94	119	0.58	924	1064	15.1
38	Q2	B + M	95	110	0.50	941	1074	14.2
39	R2	B + M	95	99	0.48	912	1041	14.6
40	R2	B + M	94	108	0.56	832	961	16.5
41	R2	B + M + F + γ	90	135	0.76	845	1001	18.3
42	S2	B + M	95	98	0.41	1082	1230	12.2
43	S2	B + M	95	107	0.53	1052	1195	12.5
44	T2	B + M	95	110	0.22	1063	1208	12.4
45	T2	B + M	95	137	0.58	1045	1188	12.5
46	U2	B + M + F	95	186	0.99	898	1020	14.3
47	V2	B + M	91	161	0.89	757	920	18.5
48	W2	B + M + F	85	143	0.71	815	980	19.0
49	X2	B + M	88	90	0.32	830	1024	13.6
50	Y2	B + M + F	92	159	0.93	699	910	18.2
51	Z2	B + M + F	80	114	0.55	843	980	20.1

TABLE 7B-continued

52	AA2	B + F	87	128	0.46	853	992	12.3
53	AB2	B + M + F	92	134	0.82	820	952	17.2
54	C2	B + M	85	182	0.85	932	1048	12.9
55	I2	B + M + F	87	135	0.42	821	962	17.5

	Hole expansion workability Hole expanding ratio λ (%)		
Steel sheet No.	Clearance: 12.5%	Clearance: 25%	Remarks
27	62	44	Invention example
28	67	43	Invention example
29	65	42	Invention example
30	46	31	Comparative example
31	70	57	Invention example
32	55	29	Comparative example
33	65	52	Invention example
34	69	55	Invention example
35	76	63	Invention example
36	39	29	Comparative example
37	66	52	Invention example
38	74	61	Invention example
39	72	59	Invention example
40	42	33	Comparative example
41	63	42	Invention example
42	69	56	Invention example
43	62	56	Invention example
44	64	52	Invention example
45	63	43	Invention example
46	74	35	Comparative example
47	60	34	Comparative example
48	62	36	Comparative example
49	48	27	Comparative example
50	67	33	Comparative example
51	51	29	Comparative example
52	43	27	Comparative example
53	52	35	Comparative example
54	39	28	Comparative example
55	42	31	Comparative example

*B: bainite, F: ferrite, P: pearlite, M: martensite, θ: cementite, γ: retained austenite

[0216] All Invention examples are high strength hot rolled steel sheets having high strength of tensile strength: 980 MPa or more and excellent hole expansion workability. On the other hand, Comparative examples out of the preferred scope of the present invention are unable to obtain predetermined tensile strength or exhibit degraded hole expansion workability.

1. A high strength hot rolled steel sheet having a tensile strength TS of 980 MPa or more, comprising a composition and a microstructure,

the composition containing, on a percent by mass basis,

C: 0.05% or more and 0.18% or less, Si: 1.0% or less,

Mn: 1.0% or more and 3.5% or less, P: 0.04% or less,

S: 0.006% or less, Al: 0.10% or less,

N: 0.008% or less, Ti: 0.05% or more and 0.20% or less,

V: more than 0.1% and 0.3% or less, and

the balance being Fe and incidental impurities, and

the microstructure comprising a primary phase and a secondary phase,

the primary phase being a bainite phase having an area fraction of more than 85%,

the secondary phase being at least one of ferrite phase, martensite phase, and retained austenite phase, the secondary phase having an area fraction of 0% or more and less than 15% in total,

the bainite phase having an average lath interval of laths of 400 nm or less, and the laths having an average long axis length of 5.0 μm or less.

2. The high strength hot rolled steel sheet according to claim **1**, wherein the composition further contains, on a percent by mass basis, at least one selected from Nb: 0.005% or more and 0.4% or less, B: 0.0002% or more and 0.0020% or less, Cu: 0.005% or more and 0.2% or less, Ni: 0.005% or more and 0.2% or less, Cr: 0.005% or more and 0.4% or less, and Mo: 0.005% or more and 0.4% or less.

3. The high strength hot rolled steel sheet according to claim **1**, wherein the composition further contains, on a percent by mass basis, at least one selected from Ca: 0.0002% or more and 0.01% or less and REM: 0.0002% or more and 0.01% or less.

4. A method for manufacturing a high strength hot rolled steel sheet, comprising:

heating a steel material having the composition according claim **1** to 1,200° C. or higher,

applying hot rolling having rough rolling and finish rolling, the finish rolling having an accumulated rolling reduction of 50% or more in a temperature range of 1,000° C. or lower and a finishing temperature of 820° C. or higher and 930° C. or lower,

starting cooling within 4.0 s after the hot rolling, performing cooling at an average cooling rate of 20° C./s or more, and

performing coiling at a coiling temperature of 300° C. or higher and 450° C. or lower.

5. A high strength hot rolled steel sheet having a tensile strength TS of 980 MPa or more, comprising a composition and a microstructure,

the composition containing, on a percent by mass basis,

C: more than 0.1% and 0.2% or less, Si: 1.0% or less,

Mn: 1.5% to 2.5%, P: 0.05% or less,

S: 0.005% or less, Al: 0.10% or less,

N: 0.007% or less, Ti: 0.07% to 0.2%,

V: more than 0.1% and 0.3% or less, and

the balance being Fe and incidental impurities,

the microstructure comprising a primary phase and the remainder other than the primary phase,

the primary phase being a bainite phase having an area fraction of 90% or more,

the remainder being at least one selected from martensite phase, austenite phase and ferrite phase and having an area fraction of 10% or less, and

cementite dispersed in the microstructure having a mass percent of 0.8% or less and an average grain size of 150 nm or less.

6. The high strength hot rolled steel sheet according to claim **5**, wherein the composition further contains, on a percent by mass basis, at least one selected from Nb: 0.005% to 0.1%, B: 0.0002% to 0.002%, Cu: 0.005% to 0.3%, Ni: 0.005% to 0.3%, Cr: 0.005% to 0.3%, and Mo: 0.005% to 0.3%.

7. The high strength hot rolled steel sheet according to claim **5**, wherein the composition further contains, on a percent by mass basis, at least one selected from Ca: 0.0003% to 0.01% and REM: 0.0003% to 0.01%.

8. A method for manufacturing a high strength hot rolled steel sheet comprising: heating a steel material, applying hot rolling having rough rolling and finish rolling, applying cooling having two stages of first stage cooling and second stage cooling, and performing coiling to produce a hot rolled steel sheet,

wherein

the steel material is specified to be a steel material having a composition containing, on a percent by mass basis,

C: more than 0.1% and 0.2% or less, Si: 1.0% or less,

Mn: 1.5% to 2.5%, P: 0.05% or less,

S: 0.005% or less, Al: 0.10% or less,

N: 0.007% or less, Ti: 0.07% to 0.2%,

V: more than 0.1% and 0.3% or less, and

the balance being Fe and incidental impurities,

the heating is a treatment to heat the steel material to 1,200° C. or higher,

the finish rolling is rolling with finishing temperature: 850° C. to 950° C.,

the first stage cooling is cooling in which cooling is started within 1.5 s of completion of the finish rolling and cooling to a first stage cooling stop temperature of 500° C. to 600° C. is performed at an average cooling rate of 20° C./s to 80° C./s,

the second stage cooling is cooling in which cooling to a second stage cooling stop temperature of 330° C. to 470° C. is performed at an average cooling rate of 90° C./s or more within 3 s of completion of the first stage cooling, and

after completion of the second stage cooling, coiling is performed, where the coiling temperature is the second stage cooling stop temperature.

9. The method for manufacturing a high strength hot rolled steel sheet, according to claim **8**, wherein the composition further contains, on a percent by mass basis, at least one selected from Nb: 0.005% to 0.1%, B: 0.0002% to 0.002%, Cu: 0.005% to 0.3%, Ni: 0.005% to 0.3%, Cr: 0.005% to 0.3%, and Mo: 0.005% to 0.3%.

10. The method for manufacturing a high strength hot rolled steel sheet, according to claim **8**, wherein the composition further contains, on a percent by mass basis, at least one selected from Ca: 0.0003% to 0.01% and REM: 0.0003% to 0.01%.

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