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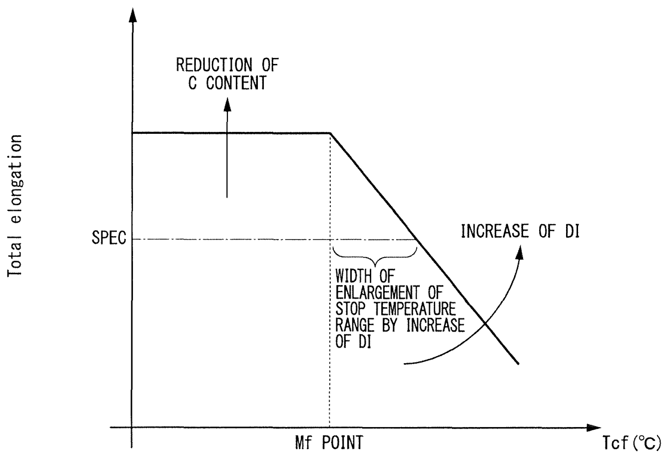
(54) **HIGH-STRENGTH STEEL SHEET**

(57) A high strength steel plate has a predetermined chemical composition, and in this high strength steel plate, DI is 2.0 to 7.8, Pcm is 0.189% or greater, a microstructure includes one or both of martensite and bainite such that a total area fraction thereof is 99% or greater, prior austenite grains have an aspect ratio of 2.0 or greater, a number fraction of cementite having a length of 1.0 μm or greater in a long axis direction with respect to cementite having a length of 0.1 μm or greater in the long axis direction is 5% or less, a plate thickness is 4.5 mm to 20 mm, a yield strength is 885 MPa or greater, a tensile strength is 950 MPa or greater, a total elongation is 12% or greater, and a Charpy absorbed energy at -20°C is 59 J/cm^2.

FIG. 1



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Description

[Technical Field of the Invention]

[0001] The present invention relates to a high strength steel plate.

[Related Art]

[0002] The size of construction machines such as crane cars or industrial machines has been increased with an increase in the height of buildings. However, in order to further increase the size, it is necessary to reduce the weight of structural members of construction machines or industrial machines. Accordingly, in order to reduce the weight of structural members, a steel to be used for construction machines or industrial machines is required to be high-strengthened.

[0003] However, in general, the total elongation is reduced in a case where the plate thickness of a steel plate is limited while increasing the strength of the steel plate to suppress the increase in the weight of members. For example, in a case where the plate thickness is limited to 25 mm or less, it is difficult to secure a total elongation of 12% or greater. In a case where the plate thickness is limited to 8 mm or less, it is more difficult to secure the total elongation. In a case where the total elongation is reduced, it is difficult to perform working. Accordingly, in a case where the steel plate is used for members of construction machines or industrial machines, the steel plate is required to have not only a strength, but also ductility such as a total elongation. In addition, in a case where the steel plate is used as a structural member, low temperature toughness is also required to prevent brittle fracture.

[0004] Based on such a background, a high strength steel plate having a tensile strength of 780 MPa or greater, or further 950 MPa, and a method of manufacturing the high strength steel plate are proposed.

[0005] For example, Patent Document 1 proposes a high strength steel plate having excellent toughness which is obtained by hot-rolling and rapidly cooling a steel containing an alloy added thererto and reducing the C content and to obtain appropriate hardenability, and a method of manufacturing the steel plate.

[0006] However, the technology described in Patent Document 1 does not consider the workability of the steel plate.

[0007] Patent Documents 2 to 4 propose a high strength hot rolled steel sheet which is manufactured by coiling a steel in a coil after hot rolling as a steel sheet which is used for construction machines or the like, and a method of manufacturing the hot rolled steel sheet. Specifically, Patent Documents 2 to 4 disclose a method of manufacturing a hot rolled steel sheet having a martensitic phase or a tempered martensitic phase as a primary phase by performing hot rolling, rapid cooling to near a martensitic transformation start temperature (Ms), holding for a predetermined period of time, and coniling in a coil. However, in these methods, coiling in a coil is required, and in the steel sheet obtained through these methods, a difference is generated between characteristics in a rolling direction and characteristics in a direction perpendicular to the rolling direction, and thus uniform characteristics are not obtained. In addition, since a holding time in a temperature range in which a fine carbide is generated is increased, the yield strength increases, and thus workability is reduced.

[0008] In conventional manufacturing of a high strength steel sheet, a heated slab was hot-rolled and subjected to accelerated cooling to room temperature to transform the microstructure to martensite, and then tempering (heat treatment) was performed to increase ductility or toughness. In a case where the microstructure of the steel sheet is transformed to martensite, the strength increases, and in order to secure ductility or toughness, tempering is preferably performed after the accelerated cooling to transform the microstructure to tempered martensite. However, in a case where the tempering is omitted from the viewpoint of shortening the construction period or suppressing an increase in the manufacturing cost, the microstructure is transformed to martensite, and thus ductility or toughness is reduced although a high strength is obtained.

[0009] Patent Document 5 proposes a high strength steel plate in which a Mn content and a Ni content are suppressed and a Mo content and a V content are increased to suppress the formation of martensite and to provide a microstructure consisting mainly of lower bainite, and a method of manufacturing the high strength steel plate.

[0010] However, since the technology described in Patent document 5 is based on the premise that the microstructure is obtained by setting a cooling stop temperature to 300°C to 450°C, a sufficient total elongation is not obtained. The inventors produced a steel plate in accordance with the disclosure of Patent Document 5 and performed a test, but a total elongation of 12% or greater was not obtained.

[0011] As described above, in a conventional high strength steel plate in which the plate thickness is limited and the microstructure consists mainly of martensite, it is difficult to secure ductility and toughness.

[0012] In addition, in a case where the steel plate is applied to the above-described structural members, welding is generally performed. In welding, at a welding joint, a tensile strength (joint strength) thereof is required to be not less than a value required for a base metal in view of reliability of the structure. However, in a case where a steel plate in which the main structure of the microstructure is martensite is welded, a welding joint may have a lower tensile strength (joint strength) than a base metal due to softening of a heat-affected zone, and a required value may not be satisfied.

[Prior Art Document]

[Patent Document]

[0013]

[Patent Document 1] Japanese Unexamined Patent Application, First Publication No. 2009-287081
[Patent Document 2] Japanese Unexamined Patent Application, First Publication No. 2011-52320
[Patent Document 3] Japanese Unexamined Patent Application, First Publication No. 2011-52321
[Patent Document 4] Japanese Unexamined Patent Application, First Publication No. 2012-77336
[Patent Document 5] PCT International Publication No. WO2012/60405

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0014] The present invention is contrived in view of the circumstances, and an object thereof is to provide a high strength steel plate which is preferably used for construction machines or industrial machines and a method of manufacturing the high strength steel plate. Specifically, an object of the invention is to provide a high strength steel plate which has a plate thickness of 4.5 to 20 mm, a yield strength of 885 MPa or greater, a tensile strength of 950 MPa or greater, a Charpy absorbed energy of 59 J/cm^2 or greater at -20°C, and a total elongation of 12% or greater, and in which the microstructure consists mainly of martensite, and a tensile strength of a welding joint after welding can be sufficiently secured, and a method of manufacturing the high strength steel plate.

[Means for Solving the Problem]

[0015] The inventors examined the relationship between the ductility of a steel plate and the accelerated cooling stop temperature. As a result, the inventors found that the ductility is reduced in a case where the accelerated cooling stop temperature is 300°C or higher or higher than a martensitic transformation completion temperature (Mf). The inventors further proceeded the examination, and found that in a case where the accelerated cooling is stopped at a temperature of 300°C or higher or a temperature higher than Mf, untransformed austenite transforms to bainite in a microstructure, voids starting from a coarse carbide (cementite) formed caused by the bainite are excessively generated, and thus the ductility is reduced.

[0016] The inventors studied ways to suppress such a reduction in the ductility. As a result, the inventors designed a component capable of increasing hardenability to suppress the above-described bainitic transformation, and found new knowledge that in a case where accelerated cooling to a temperature which is lower than 300°C and not higher than Mf is performed after hot rolling, the microstructure can be allowed to consist mainly of martensite, and thus the ductility of a high strength steel plate can be secured.

[0017] The invention is contrived based on such knowledge, and the gist thereof is as follows.

[0018]

(1) A high strength steel plate according to an embodiment of the invention consisits of, as a chemical composition, by mass%: C: 0.050% to 0.100%, Si: 0% to 0.50%, Mn: 1.20% to 1.70%, P: 0.020% or less, S: 0.0050% or less, N: 0% to 0.0080%, B: 0.0003% to 0.0030%, Ti: 0.003% to 0.030%, Nb: 0.003% to 0.050%, Cr: 0% to 2.00%, Mo: 0% to 0.90%, Al: 0% to 0.100%, Cu: 0% to 0.50%, Ni: 0% to 0.50%, V: 0% to 0.100%, W: 0% to 0.50%, Ca: 0% to 0.0030%, Mg: 0% to 0.0030%, REM: 0% to 0.0030%, and a remainder consisting of Fe and impurities, one or both of Cr and Mo is contained in an amount of 0.20% or greater in total, the Cr content is 0.80% or less in a case where the Mo content is greater than 0.50%, DI which is obtained by the Formula 1 is 2.0 to 7.8, Pcm which is obtained by the Formula 2 is 0.189% or greater, a microstructure includes one or both of martensite and bainite such that a total area fraction thereof is 99% or greater, an aspect ratio of prior austenite grains is 2.0 or greater, a number fraction of cementite having a length of 1.0 μm or greater in a long axis direction with respect to cementite having a length of 0.1 μm or greater in the long axis direction is 5% or less, a plate thickness is 4.5 mm to 20 mm, a yield strength is 885 MPa or greater, a tensile strength is 950 MPa or greater, a total elongation is 12% or greater, and a Charpy absorbed energy at -20°C is 59 J/cm^2.

$$DI=[C]^{0.5}\times\{0.34\times(1+0.64\times[Si])\times(1+4.1\times[Mn])\times(1+0.27\times[Cu])\times(1+0.52\times[Ni])\times(1+2.33\times[Cr])\times(1+3.14\times[Mo])\}\times1.2 \ \ldots \text{(Formula 1)}$$

$$Pcm=[C]+[Si]/30+[Mn]/20+[Cu]/20+[Ni]/60+[Cr]/20+[Mo]/15+[V]/10+5\times[B] \ \ldots \text{(Formula 2)}$$

In the Formulae 1 and 2, each of [C], [Si], [Mn], [Cu], [Ni], [Cr], [Mo], [V], and [B] represents a content of each element by mass%, and 0 is substituted in a case where the element is not contained.

(2) In the high strength steel plate according to (1), the microstructure may include 90% or greater of martensite in terms of area fraction.

(3) In the high strength steel plate according to (1) or (2), the chemical composition may include Cu: 0% to 0.25% by mass%.

(4) In the high strength steel plate according to any one of (1) to (3), the chemical composition may include Ni: 0% to 0.25% by mass%.

(5) In the high strength steel plate according to any one of (1) to (4), the chemical composition may include V: 0% to 0.050% by mass%.

(6) In the high strength steel plate according to any one of (1) to (5), the chemical composition may include W: 0% to 0.05% by mass%.

(7) In the high strength steel plate according to any one of (1) to (6), the plate thickness may be 4.5 mm to 15 mm.

(8) In the high strength steel plate according to any one of (1) to (7), in a case where the Mo content is represented by [Mo] and the Cr content is represented by [Cr], [Mo]/[Cr] may be 0.20 or greater.

(9) In the high strength steel plate according to (8), a Charpy absorbed energy at -40°C may be 59 J/cm^2 or greater.

(10) In the high strength steel plate according to any one of (1) to (9), the Pcm may be 0.196% or greater.

[Effects of the Invention]

[0019] According to the aspect of the invention, it is possible to provide a high strength steel plate which has a yield strength of 885 MPa or greater, a tensile strength of 950 MPa or greater, and a total elongation of 12% or greater without containing a large amount of expensive alloying elements. This steel plate exhibits excellent toughness such that a Charpy absorbed energy at -20°C is 59 J/cm^2 or greater. In addition, by adjusting Pcm, that is a hardenability index, to be 0.189% or greater, and preferably 0.196% or greater, a tensile strength of 950 MPa or greater can be secured at a welding joint where a high strength steel plate according to the invention is a base metal with a predetermined heat input or less in welding.

[0020] Furthermore, by controlling [Mo]/[Cr] that is a ratio of a Mo content [Mo] to a Cr content [Cr], it is possible to provide a high strength steel plate having more excellent toughness such that a Charpy absorbed energy at -40°C is 59 J/cm^2 or greater.

[0021] Accordingly, the invention can provide a high strength steel plate which is preferably used for a structural member in construction machines or industrial machines to contribute to an increase in the size or a reduction in the weight of the construction machines or industrial machines without a significant increase in manufacturing cost, and thus very significantly contributes to the industry.

[Brief Description of the Drawings]

[0022]

FIG. 1 is a diagram illustrating the relationship between: a total elongation; and an accelerated cooling stop temperature Tcf, a hardenability index DI, and a C content.

FIG. 2 is a diagram showing the relationship between [Mo]/[Cr] and a Charpy absorbed energy (vE-40) at -40°C.

FIG. 3 is a diagram showing the relationship between an accelerated cooling stop temperature and a total elongation.

FIG. 4A is an SEM photograph showing the influence of an accelerated cooling stop temperature on the shape of cementite in a case where the accelerated cooling stop temperature is 290°C.

FIG. 4B is an SEM photograph showing the influence of an accelerated cooling stop temperature on the shape of cementite in a case where the accelerated cooling stop temperature is 400°C.

FIG. 5 is a photograph of a void generated from the vicinity of coarse cementite.

[Embodiments of the Invention]

[0023] Hereinafter, a high strength steel plate according to an embodiment of the invention (hereinafter, may be referred to as a high strength steel plate according to this embodiment) will be described in detail.
[0024] First, a chemical composition (components) of a high strength steel plate according to this embodiment will be described. Hereinafter, the symbol % related to the content means mass% unless otherwise noted.

(C: 0.050% to 0.100%)

[0025] C is a useful element for increasing a strength of steel, and is a very important element for determining a total elongation of steel having a martensite structure. In the high strength steel plate according to this embodiment, the C content is required to be 0.050% or greater to obtain a sufficient strength. In order to further increase the strength, the C content is preferably 0.060% or greater, 0.065% or greater, or 0.070% or greater. In a case where the C content is greater than 0.100%, the ductility and toughness of steel deteriorate due to the generation of an excessive amount of a carbide. Therefore, the C content is required to be 0.100% or less to obtain a good total elongation and good toughness. In order to further improve the ductility, the C content is preferably adjusted to be 0.095% or less, 0.090% or less, or 0.085% or less.

(Si: 0.50% or less)

[0026] In a case where an excessive amount of Si is contained, the ductility or toughness of steel is reduced. Therefore, the Si content is limited to 0.50% or less. It is not necessary to particularly determine the lower limit of the Si content, and the lower limit of the Si content is 0%. However, in a case where Si is used for deoxidation, the Si content is preferably adjusted to be 0.03% or greater to obtain a sufficient effect. In addition, Si is also an element which suppresses the generation of a carbide, and in order to obtain this effect, the Si content is preferably adjusted to be 0.10% or greater, and more preferably 0.20% or greater. In a case where it is not necessary to obtain the effects, the upper limit of the Si content may be adjusted to be 0.45%, 0.40%, or 0.35%.

(Mn: 1.20% to 1.70%)

[0027] Mn is an important element for improving the hardenability of steel. The Mn content is adjusted to be 1.20% or greater to obtain a high strength by increasing a martensite area fraction in a microstructure. The Mn content is preferably adjusted to be greater than 1.20%, 1.25% or greater, or 1.30% or greater, and more preferably 1.35% or greater or 1.39% or greater. In a case where the Mn content is too high, ductility and toughness may be reduced. Accordingly, the Mn content is adjusted to be 1.70% or less. More preferably, the Mn content is adjusted to be 1.60% or less, 1.55% or less, or 1.50% or less.

(P: 0.020% or less)

(S: 0.0050% or less)

[0028] P and S are elements inevitably contained as impurities in steel, and deteriorate the toughness of steel. In addition, P and S are elements which deteriorate the toughness of a heat-affected zone in a case where welding is performed. Therefore, the P content is limited to 0.020% or less, and the S content is limited to 0.0050% or less. In order to further improve the toughness, the P content may be adjusted to be 0.015% or less, and the S content may be adjusted to be 0.0030% or less. Since the P content and the S content are preferably low, and thus preferably reduced as much as possible. Accordingly, it is not necessary to particularly determine the lower limits of the P content and the S content, and the lower limits of the P content and the S content are 0%. However, from the viewpoint of cost of dephosphorization or desulfurization, the P content may be adjusted to be 0.001% or greater, and the S content may be adjusted to be 0.0001% or greater.

(B: 0.0003% to 0.0030%)

[0029] B is an element which is segregated in the grain boundary to increase the hardenability of steel, and is a useful element for exhibiting the effect even in a case where the amount thereof is very small. In the high strength steel plate according to this embodiment, the B content is adjusted to be 0.0003% or greater to increase martensite in a microstructure. Preferably, the B content is adjusted to be 0.0005% or greater. In a case where the B content is too high, the hardenability improving effect is saturated, and precipitates such as a nitride or a carboboride are formed. Thus, ductility or toughness is reduced. Therefore, the B content is adjusted to be 0.0030% or less. The B content is preferably adjusted to be 0.0020% or less or 0.0015% or less.

(Ti: 0.003% to 0.030%)

[0030] Ti is an element which forms a nitride, and is an element which fixes N in steel as TiN and suppresses the generation of BN. As described above, though B is an element which increases hardenability, the effect of B is not obtained in a case where BN is formed. In the high strength steel plate according to this embodiment, the Ti content is required to be 0.003% or greater to secure hardenability by suppressing the formation of BN. The Ti content is preferably adjusted to be 0.005% or greater, and more preferably 0.010% or greater. In a case where the Ti content is too high, TiN becomes coarse, and thus ductility or toughness may be reduced. Accordingly, the Ti content is adjusted to be 0.030% or less. The Ti content is preferably adjusted to be 0.020% or less.

(Nb: 0.003% to 0.050%)

[0031] Nb is an element which significantly improves the hardenability of steel by being contained together with B. In the high strength steel plate according to this embodiment, the Nb content is adjusted to be 0.003% or greater to increase a martensite area fraction in a microstructure. Nb is also an element which contributes to grain refining and increases toughness by forming a fine nitride. In order to obtain this effect, the Nb content is preferably adjusted to be 0.005% or greater. More preferably, the Nb content is adjusted to be 0.010% or greater or 0.015% or greater. In a case where the Nb content is too high, the nitride becomes coarse, and thus ductility or toughness may be reduced. Accordingly, the Nb content is adjusted to be 0.050% or less. The Nb content is preferably adjusted to be 0.040% or less, 0.035% or less, or 0.030% or less.

(Cr: 2.00% or less)

(Mo: 0.90% or less)

(Total Content of One or Both of Cr and Mo is 0.20% or Greater, and In Case Where Mo Content is Greater Than 0.50%, Cr Content is 0.80% or Less)

[0032] Cr and Mo are important elements for improving hardenability, and one or both of Cr and Mo are contained. In the high strength steel plate according to this embodiment, the total content of Cr and Mn is adjusted to be 0.20% or greater to increase a martensite area fraction in a microstructure. The total content of Cr and Mn is preferably adjusted to be 0.30% or greater, and more preferably 0.40% or greater. In consideration of a case where either Cr or Mo is contained, the lower limits of the Cr content and the Mo content are 0%. If necessary, the lower limit of the Cr content may be adjusted to be 0.20% or 0.30%, and similarly, the lower limit of the Mo content may be adjusted to be 0.20% or 0.30%.

[0033] In addition, in a case where the Cr content is greater than 2.00% or the Mo content is greater than 0.90%, a fine carbide is generated, and thus ductility and toughness are reduced. Therefore, the Cr content and the Mo content are adjusted to be 2.00% or less and 0.90% or less, respectively. The Cr content is preferably adjusted to be 1.50% or less or 1.00% or less, and more preferably 0.90% or less or 0.80%. The Mo content is preferably adjusted to be 0.70% or less, and more preferably 0.60% or less or 0.50%.

[0034] In a case where both Cr and Mo are contained, toughness is reduced in a case where the content is too high. Accordingly, in a case where the Mo content is greater than 0.50%, the Cr content is required to be 0.80% or less. In this case, the Cr content may be adjusted to be 0.70% or less. In a case where the Cr content is greater than 0.80%, the Mo content may be adjusted to be 0.50% or less, and in a case where the Cr content is greater than 1.20%, the Mo content may be adjusted to be 0.40% or less. The total content of Cr and Mo may be adjusted to be 2.50% or less, 2.00% or less, 1.50% or less, 1.30% or less, or 1.10% or less.

(N: 0.0080% or less)

[0035] N is inevitably contained as impurities. N forms BN and inhibits the hardenability improving effect of B. Accordingly, the N content is limited to 0.0080% or less. The N content is preferably limited to 0.0060% or less, and more preferably 0.0050% or less. The N content is preferably reduced as much as possible, and the lower limit thereof is 0%. However, from the viewpoint of cost of denitrification, the N content may be adjusted to be 0.0001% or greater. The N content may be adjusted to be 0.0020% or greater for refining of a microstructure by a nitride.

[0036] The above elements are contained as essential elements and impurities of the high strength steel plate according to this embodiment, and basically, the high strength steel plate according to this embodiment has components including the above-described essential elements and a remainder consisting of Fe and impurities (the above-described impurity elements and optional impurity elements other than the above-described impurity elements). However, for deoxidation, an improvement in the strength and/or ductility, refining of a microstructure, control of the form of a sulfide, or the like, the high strength steel plate according to this embodiment may further contain, other than the above-described components, one or more of 0.100% or less of Al, 0.50% or less of Cu, 0.50% or less of Ni, 0.100% or less of V, 0.50% or less of W, 0.0030% or less of Ca, 0.0030% or less of Mg, and 0.0030% or less of REM instead of a part of Fe. Since these elements are not essential elements, the contents of the elements may be 0%.

(Al: 0.100% or less)

[0037] Al is a deoxidizing element. In a case where Al is used for deoxidation, the Al content is preferably adjusted to be 0.010% or greater to obtain a sufficient effect. In a case where the Al content is too high, ductility or toughness is reduced due to the formation of an oxide or a nitride. Therefore, the Al content is limited to 0.100% or less even in a case where Al is contained. The Al content is preferably limited to 0.080% or less, more preferably 0.050% or less, and even more preferably 0.030% or less.

(Cu: 0.50% or less)

(Ni: 0.50% or less)

[0038] Cu and Ni are elements which improve the hardenability of steel. In a case where a martensite area fraction in a microstructure is increased by increasing the hardenability, the Cu content and the Ni content are preferably adjusted to be 0.10% or greater, respectively. Since Cu and Ni are expensive elements, the Cu content and the Ni content are preferably adjusted to be 0.50% or less, respectively, even in a case where Cu and Ni are contained. The Cu content and the Ni content are more preferably adjusted to be 0.40% or less, and even more preferably 0.30% or less, respectively.

(V: 0.100% or less)

[0039] V is an element which forms a carbide or a nitride. The V content is preferably adjusted to be 0.005% or greater in a case where toughness is increased by grain refining by a carbide or a nitride. In a case where the V content is too high, ductility or toughness is reduced. However, since V has less adverse effects than Nb or Ti, the upper limit of the V content is limited to 0.100% in a case where V is contained. The V content is preferably adjusted to be 0.050% or less.

(W: 0.50% or less)

[0040] W is an element which improves the hardenability of steel. In order to obtain this effect, the W content is preferably adjusted to be 0.05% or greater. In a case where the W content is too high, weldability deteriorates. Therefore, the W content is adjusted to be 0.50% or less or 0.30% or less even in a case where W is contained. If necessary, the W content may be adjusted to be 0.02% or less or 0.01% or less.

(Ca: 0.0030% or less)

[0041] Ca is an element which controls the form of an oxide or a sulfide. In order to obtain this effect, the Ca content is preferably adjusted to be 0.0001% or greater. The Ca content is more preferably adjusted to be 0.0005% or greater, and even more preferably 0.0010% or greater. In a case where the Ca content is too high, the effect is saturated, and ductility or toughness may be reduced due to the formation of inclusions. Therefore, the Ca content is adjusted to be 0.0030% or less even in a case where Ca is contained.

(Mg: 0.0030% or less)

[0042] Mg is an element which acts to increase the toughness of steel by refining the microstructure. In order to obtain this effect, the Mg content is preferably adjusted to be 0.0005% or greater. In a case where the Mg content is too high, the effect is saturated, and ductility or toughness may be reduced due to the formation of inclusions. Therefore, the Mg content is adjusted to be 0.0030% or less even in a case where Mg is contained.

(REM: 0.0030% or less)

[0043] REM (rare earth metal) is an element which acts to increase the toughness of steel by controlling the form of a sulfide, particularly, MnS. In order to obtain this effect, the REM content is preferably adjusted to be 0.0001 % or greater. In a case where the REM content is too high, inclusions including REM may become coarse, and thus ductility or toughness may be reduced. Therefore, the REM content is adjusted to be 0.0030% even in a case where REM is contained.

[0044] Elements other than the above elements may be contained in a small amount within a range not impairing the actions and effects.

[0045] In the high strength steel plate according to this embodiment, with the elements adjusted to be within the above-described ranges, DI and Pcm, which are determined by a chemical composition, are required to satisfy the following ranges, respectively.

(DI: 2.0 to 7.8)

[0046] DI is a hardenability index, and is obtained by (Formula 1). Here, each of [C], [Si], [Mn], [Cu], [Ni], [Cr], and [Mo] in the formula represents a content (mass%) of each element, and 0 is substituted in a case where the element is not contained.

[0047] As qualitatively shown in FIG. 1, in a case where a hardenability index DI is increased, a reduction in the total elongation can be suppressed even in a case where an accelerated cooling stop temperature Tcf is increased (that is, moved to the right in FIG. 1). In a case where the accelerated cooling stop temperature Tcf is increased, an excessive increase in the strength is suppressed, and toughness and/or ductility can be increased. In order to keep a good balance among a strength, ductility, and toughness, DI is preferably 2.0 or greater. DI is more preferably 3.0 or greater, and even more preferably 4.0 or greater. In a case where the hardenability excessively increases, the strength excessively increases, and thus the toughness may be reduced. Accordingly, DI is preferably 7.8 or less. DI is more preferably 7.0 or less, and even more preferably 6.5 or less.

$$DI=[C]^{0.5}\times\{0.34\times(1+0.64\times[Si])\times(1+4.1\times[Mn])\times(1+0.27\times[Cu])\times(1+0.52\times[Ni])\times(1+2.33\times[Cr])\times(1+3.14\times[Mo])\}\times1.2 \ \ldots \text{(Formula 1)}$$

(Pcm: 0.189% or greater)

[0048] In general, a tensile strength (joint strength) of a welding joint is required to be not less than a required tensile strength for a base metal provided in welding. The inventors found that in a case where welding is performed on a steel plate in which a main structure of a microstructure is martensite, a tensile strength (joint strength) of a welding joint may be less than a tensile strength of a base metal due to softening of a heat-affected zone. Accordingly, the inventors manufactured welding joints using various high strength steel plates by changing weld heat input, and performed a test. As a result, the inventors found that by increasing the hardenability of a steel plate, specifically, by adjusting Pcm, which is obtained by (Formula 2), to be 0.189% or greater, the softening of a heat-affected zone is suppressed, and in a case where the welding is performed with 7.0 kJ/cm weld heat input that is the lower limit value of a weld heat input range frequently applied to the manufacturing of a structural member of construction machines or industrial machines, the tensile strength of a welding joint can be 950 MPa or greater.

$$Pcm=[C]+[Si]/30+[Mn]/20+[Cu]/20+[Ni]/60+[Cr]/20+[Mo]/15+[V]/10+5\times[B] \ \ldots \text{(Formula 2)}$$

[0049] Each of [C], [Si], [Mn], [Cu], [Ni], [Cr], [Mo], [V], and [B] represents a content (mass%) of each element, and 0 is substituted in a case where the element is not contained.

[0050] The inventors further conducted studies on the weld heat input and the strength of the welding joint, and found that the strength of the welding joint can be evaluated by JS which is calculated by (Formula a) using Pcm obtained by (Formula 2) and weld heat input Hi [kJ/cm] from the component composition of the high strength steel plate used in welding, and a joint strength of 950 MPa or greater can be secured at an actual welding joint in a case where JS is 950 MPa or greater.

$$JS=(4.3/Hi+3.4)\times(1680.7\times Pcm-81.5)\ \ldots\ \text{(Formula a)}$$

[0051] As can be seen from the above formula, it is found that the weld heat input is preferably reduced as much as possible in order to secure the strength of the welding joint. However, there is a lower limit in the weld heat input in order to secure the soundness of the welding joint. It is not easy to reduce the weld heat input to be less than 7.0 kJ/cm in order to secure the welding productivity or the like in the manufacturing of construction machines or industrial machines. In a case where the weld heat input is 7.0 kJ/cm, Pcm necessary for adjusting JS to be 950 MPa or greater is 0.189% from the above formula. That is, by adjusting Pcm to be 0.189% or greater, a joint strength of 950 MPa or greater can be secured.

[0052] In addition, by adjusting Pcm to be 0.196% or greater, a joint strength of 950 MPa or greater can be secured even in a case where the welding is performed with 10.0 kJ/cm weld heat input with which no special management is required. That is, by adjusting Pcm to be 0.196% or greater, a welding joint strength of 950 MPa or greater can be secured without special welding management.

[0053] Pcm may be adjusted to be 0.200% or greater, 0.205% or greater, 0.210% or greater, or 0.215% or greater to secure the strength of the welding joint even with higher weld heat input. It is preferable that the weld heat input be high since the number of welding paths can be reduced, and thus the productivity can be improved. It is not necessary to particularly determine the upper limit of Pcm, and the upper limit may be 0.250% or less or 0.240% or less to prevent weld cracking or the like.

([Mo]/[Cr]: 0.20 or higher)

[0054] The inventors further proceeded the examination and studies of the influence of Cr and Mo as hardenability increasing elements on toughness. As a result, the inventors found that in a case where hardenability (DI) is constant, a ratio of Mo to Cr has an influence on toughness. Specifically, it was found that in a case where a ratio ([Mo]/[Cr]) of the Mo content [Mo] to the Cr content [Cr] by mass% is high, a substructure (packet or block) of the martensite is made fine, and as a result, toughness is improved. For a further improvement of toughness, the ratio may be 0.40 or higher, 0.80 or higher, or 1.00 or higher.

[0055] FIG. 2 is a diagram showing the relationship between [Mo]/[Cr] and a Charpy absorbed energy at -40°C. In FIG. 2, the symbol "○" represents an actual measurement value, and the symbol "●" represents an average of the actual measurement values.

[0056] As shown in FIG. 2, it is found that there is a tendency that the Charpy absorbed energy at -40°C increases with an increase of [Mo]/[Cr], and in a case where [Mo]/[Cr] is 0.20 or higher, the Charpy absorbed energy at -40°C is 59 J/cm^2 or greater. Accordingly, in a case where low temperature toughness is obtained, [Mo]/[Cr] is preferably adjusted to be 0.20 or higher. Mo is an element which more easily forms a fine carbide or cluster than Cr. Accordingly, in a case where the Mo content is excessively higher than the Cr content, toughness may be reduced, and thus [Mo]/[Cr] may be adjusted to be 2.00 or lower or 1.50 or lower.

[0057] The Charpy absorbed energy is measured by a Charpy test performed based on JIS Z 2242. A test piece collected from a thickness middle portion, in which the plate thickness of the steel plate from which the test piece has been collected is 8 mm, and a longitudinal direction is a rolling direction, is a sub-sized test piece of 10 mm×5 mm.

(Total Area Fraction of One or Both of Martensite and Bainite: 99% or greater and Total elongation: 12% or greater)

[0058] The inventors conducted studies on the relationship between the hardenability and the microstructure of a high strength steel plate, and a total elongation. As a result, the inventors found that in a case where the hardenability is poor, the total elongation is reduced, and a reduction in the total elongation, that is, a reduction in the ductility occurs due to the generation of voids starting from a coarse carbide generated caused by the bainite as shown in FIGS. 4A and 4B. In addition, the inventors obtained knowledge that it is necessary to suppress the formation of bainite causing the formation of coarse cementite in order to increase the ductility of a high strength steel plate. In order to suppress the formation of bainite causing the formation of coarse cementite, a structure mainly including martensite in which 90% or more of a microstructure is martensite is preferably provided. In addition, in order to increase the strength of a steel plate, the martensite area fraction in the microstructure is preferably adjusted to be 90% or greater, more preferably 92% or greater, and even more preferably 94% or greater.

[0059] However, both the martensite and the bainite are continuous cooling transformation structures, and it may be difficult to accurately distinguish the martensite and the bainite by observing the microstructures. In such a case, it can be judged that the formation of bainite causing the formation of coarse cementite is suppressed in a case where the total area fraction of martensite and bainite is 99% or greater and the total elongation is 12% or greater.

[0060] Accordingly, in the high strength steel plate according to this embodiment, the total area fraction of one or both of martensite and bainite is adjusted to be 99% or greater, and the total elongation as a structure index is adjusted to be 12% or greater. In a case where it is possible to sufficiently distinguish the martensite and the bainite by observing the microstructures, the martensite area fraction is preferably 90% or greater.

[0061] In the high strength steel plate according to this embodiment, the martensite of the microstructure is as quenched, and is different from tempered martensite obtained after tempering treatment. Tempered martensite is not preferable since cementite grows by tempering for a long period of time.

[0062] The remainder other than the above microstructures may include one or more of ferrite, pearlite, and residual austenite.

[0063] The distinguishment of the microstructure and the measurement of the martensite area fraction are performed using an optical microscope. Specifically, near a 1/4 t-portion in a cross-section parallel to a rolling direction (a portion at a depth of 1/4 of a plate thickness t from a steel plate surface in a plate thickness direction) is subjected to nital etching, and two regions within a range of 120 μm×100 μm are photographed at 500-fold magnification using an optical microscope to measure an area fraction of a microstructure in which an acicular lath structure is developed. With respect to the acicular structure, the cross-section of the steel plate is subjected to electrolytic polishing, and then a portion near the 1/4 t-portion in the cross-section of the steel plate is observed by a scanning electron microscope (SEM). Here, the magnification is 5,000 times, and the photographing is performed within a range of 50 μm×40 μm. In a case where a long axis direction of cementite is oriented in two or more directions in the block, the acicular structure is defined as martensite, and an area fraction of the region is obtained. The product of the acicular structure area fraction measured using the optical microscope and the martensite area fraction measured using SEM is an area fraction of the martensite structure of this steel.

[0064] In the above-described structure observation using a scanning electron microscope, the orientation of the long axis direction of cementite in two or more directions in the block may not be clearly distinguished. In this case, using an optical microscope, the area fraction of a microstructure in which an acicular lath structure is developed is defined as the total area fraction of martensite and bainite.

(Number Fraction of Cementite Having Length of 1.0 μm or Greater in Long Axis Direction with respect to Cementite Having Length of 0.1 μm or Greater in Long Axis Direction: 5% or less)

[0065] As described above, in order to increase the ductility of a steel plate, it is important to suppress the formation of bainite causing the formation of coarse cementite is suppressed and to provide a microstructure mainly including martensite. However, in order to further increase the ductility, it is effective to suppress the generation of voids starting from a coarse carbide (particularly, cementite).

[0066] The inventors found that by controlling an accelerated cooling stop temperature, the number fraction of the coarse carbide (particularly, cementite) having a length of 1.0 μm or greater in a long axis direction can be reduced, and as a result, the generation of voids can be suppressed and the total elongation can be improved. Specifically, the inventors found that the total elongation can be improved by adjusting the number fraction of cementite having a length of 1.0 μm or greater in a long axis direction in cementite having a length of 0.1 μm or greater in a long axis direction to be 5% or less.

[0067] As will be described later in detail, in the invention, by stopping accelerated cooling at a temperature which is not higher than Mf and lower than 300°C, it is possible to provide a structure mainly including martensite in which the generation of a coarse carbide is suppressed. That is, the generation of voids starting from coarse cementite having a length of 1.0 μm in a long axis direction can be suppressed by controlling an accelerated cooling stop temperature.

[0068] The number density of cementite is measured using a scanning electron microscope (SEM). Specifically, a cross-section of the steel plate is subjected to electrolytic polishing, and then a portion near a 1/4 t-portion in the cross-section of the steel plate is photographed within a range of 50 μm×40 μm at 5,000-fold magnification by a scanning electron microscope (SEM). Based on the contrast in the obtained image, the number of precipitates as cementite having an aspect ratio of 2.0 or greater and a length of 0.1 μm or greater in a long axis direction is counted using image analysis software. Similarly, the number of cementite having an aspect ratio of 2.0 or greater and a length of 1.0 μm or greater in a long axis direction is counted. The obtained number of precipitates of 1.0 μm or greater is divided by the number of cementite of 0.1 μm or greater, and thus the number fraction (%) of cementite of 1.0 μm or greater is obtained. The shape of the carbide is not particularly limited. However, in a case where the carbide has an ellipsoidal shape, the "length in a long axis direction" refers to a major axis.

(Aspect Ratio of Prior Austenite Grains is 2.0 or Greater)

[0069] In the high strength steel plate according to this embodiment, the aspect ratio of prior austenite grains is adjusted to be 2.0 or greater. In a case where the aspect ratio is less than 2.0, toughness may be reduced.

[0070] In a case where online accelerated cooling (direct quenching) is performed after rolling in a non-recrystallization region, the aspect ratio of prior austenite grains can be adjusted to be 2.0 or greater. In a case where quenching is performed after rolling, cooling, and subsquent reheating, the structure worked by rolling is not taken over, and the aspect ratio of prior austenite grains becomes less than 2.0.

[0071] The aspect ratio of prior austenite grains is measured by the following method. That is, near a 1/4 t-portion in a cross-section parallel to a rolling direction, which is positioned at a depth of 1/4 of a plate thickness t from a surface in a plate thickness direction, is etched with nital, and two regions within a range of 120 μm$\times$100 μm are photographed at 500-fold magnification using an optical microscope. From the obtained image, long axis lengths and short axis lengths of at least 50 prior austenite grains are measured, and the long axis length is divided by the short axis length to obtain an aspect ratio of each grain. An average of the aspect ratios of the prior austenite grains is obtained.

[0072] Next, a plate thickness and mechanical properties of the high strength steel plate according to this embodiment will be described.

(Plate thickness: 4.5 to 20 mm)

[0073] In general, a high strength steel plate which is used for cranes or the like has a plate thickness of 4.5 to 20 mm. Therefore, the high strength steel plate according to this embodiment has a plate thickness of 4.5 to 20 mm. However, the thickness is preferably 4.5 to 15 mm in view of contribution to a reduction in the weight.

(Yield Strength: 885 MPa or greater)

(Tensile Strength: 950 MPa or greater)

[0074] In addition, high-strengthening is required to contribute to an increase in the size or a reduction in the weight of construction machines or industrial machines. In order to obtain a significantly economical effect, it is necessary to adjust the yield strength to be 885 MPa or greater and to adjust the tensile strength to be 950 MPa or greater. Although it is not necessary to particularly determine the upper limit of the yield strength, and the upper limit may be 1,100 MPa or less. Although it is not necessary to particularly determine the upper limit of the tensile strength, and the upper limit may be 1,300 MPa or less or 1,250 MPa or less.

(Total elongation: 12% or greater)

[0075] In order to apply a high strength steel plate to members of construction machines or industrial machines, workability such as bendability is required, and thus the total elongation is adjusted to be 12% or greater. In addition, as described above, the total elongation may be a structure index indicating whether the formation of bainite, which causes the formation of coarse cementite is suppressed.

[0076] The yield strength, the tensile strength, and the total elongation are measured by performing a tensile test based on JIS Z 2241. The value of the total elongation measured by the tensile test depends on the shape of a test piece. The limit (12% or greater) of the total elongation is a value in a case where a No. 5 test piece of JIS Z2241 (a flat test piece in which original gauge length is 50 mm, a parallel portion has a width of 25 mm, and the thickness of the test piece is equal to that of the steel plate) is used as a tensile test piece.

[0077] The elongation conversion formula based on a difference in the test piece shape is also specified in ISO2566-1. Regarding the elongation of 12% in a No. 5 test piece of JIS Z2241, in a case where a No. 13B test piece of JIS Z2241 (a flat test piece in which original gauge length is 50 mm, a parallel portion has a width of 12.5 mm, and the thickness of the test piece is equal to that of the steel plate) is used as a tensile test piece, the elongation can be converted into 10.4%, and in a case where a No. 13A test piece of JIS Z2241 (a flat test piece in which original gauge length is 80 mm, a parallel portion has a width of 20 mm, and the thickness of the test piece is equal to that of the steel plate) is used as a tensile test piece, the elongation can be converted into 9.5%.

(Charpy Absorbed Energy at -20°C: 59 J/cm^2 or greater)

[0078] In a case where construction machines or industrial machines are used in cold climates, the high strength steel plate may be required to have low temperature toughness. Therefore, the Charpy absorbed energy at -20°C is preferably 59 J/cm^2. More preferably, the Charpy absorbed energy at -40°C is preferably 59 J/cm^2 or greater.

[0079] The Charpy absorbed energy is measured by collecting a test piece in which a longitudinal direction is a rolling direction from a thickness middle portion, and performing a Charpy test based on JIS Z 2242 at -20°C or -40°C. It may be difficult to collect a full-sized test piece of 10 mm$\times$10 mm depending on the plate thickness of the steel plate, and in such a case, a sub-sized test piece is used. The Charpy absorbed energy is a value (J/cm^2) obtained by dividing the absorption energy by a cross-sectional area (cm^2) of the test piece in a bottom part of a V-notch. For example, in a case where a full-sized test piece of 10 mm×10 mm is used, a measured Charpy absorbed energy value (J) is divided by 1 cm×0.8 cm=0.8 cm2, and in a case where a sub-sized test piece of 10 mm×5 mm is used, the measured Charpy absorbed energy value (J) is divided by 0.5 cm×0.8 cm=0.4 cm^2.

[0080] Next, a preferable method of manufacturing a high strength steel plate according to this embodiment will be described.

[0081] The high strength steel plate according to this embodiment can be manufactured as follows: a molten steel having a chemical composition within the above-described range is melted in the usual manner, a slab obtained by casting the molten steel is heated to perform hot rolling, accelerated cooling is performed, and after the accelerated cooling is stopped, air cooling to room temperature is performed. In the manufacturing of the high strength steel plate according to this embodiment, a heat treatment such as tempering is not performed after the accelerated cooling is stopped or after the air cooling to room temperature is performed. In a case where a treatment is performed, martensite changes to tempered martensite. That is, the high strength steel plate according to this embodiment is manufactured through non-heat treated manufacturing steps in which a heat treatment is omitted to shorten the construction period or reduce the manufacturing cost. The high strength steel plate according to this embodiment manufactured through the non-heat treated manufacturing steps may be referred to as a non-heat treated high strength steel plate.

[0082] Hereinafter, preferable conditions of each step will be described.

(Slab Heating Temperature: 1,100°C to 1,250°C)

[0083] The high strength steel plate according to this embodiment is required to contain a predetermined amount of alloying elements to increase hardenability. Therefore, a carbide or a nitride of alloying elements is generated in a slab provided in hot rolling. In heating of the slab, it is necessary to decompose the carbide or the nitride in order to form a solid solution in the steel, and the heating temperature is adjusted to be 1,100°C or higher. In a case where the heating temperature of the slab is too high, the grain size becomes coarse, and thus toughness may be reduced. Accordingly, the heating temperature is adjusted to be 1,250°C or higher.

(Finishing Temperature: Ar3 (°C) or higher)

(Accelerated Cooling Start Temperature: Ar3 (°C) or higher)

[0084] A heated slab is hot-rolled. After the hot rolling, it is necessary to start accelerated cooling at a temperature at which the microstructure is austenite in order to provide a microstructure mainly including martensite through the accelerated cooling. Accordingly, the hot rolling should be ended at a temperature at which the microstructure is austenite. For this, the hot rolling finishing temperature is adjusted to be Ar3 (°C) or higher. Ar3 (°C) is a temperature at which transformation from austenite to ferrite starts during cooling, and can be obtained from thermal expansion behavior. In addition, Ar3 (°C) can be simply obtained by (Formula b).

$$\mathrm{Ar3}=868-396\times[\mathrm{C}]+24.6\times[\mathrm{Si}]-68.1\times[\mathrm{Mn}]-36.1\times[\mathrm{Ni}]-20.7\times[\mathrm{Cu}]-24.8\times[\mathrm{Cr}]+29.6\times[\mathrm{Mo}] \ \ldots \ (\text{Formula b})$$

[0085] Here, each of [C], [Si], [Mn], [Ni], [Cu], [Cr], and [Mo] represents a content (mass%) of each element, and 0 is substituted in a case where the element is not contained.

[0086] The hot rolling may be performed in the usual manner, and it is preferable that recrystallization region rolling be performed with a cumulative rolling reduction of 50% to 80% within a temperature range not lower than 1,050°C, or non-recrystallization region rolling be performed with a cumulative rolling reduction of 50% to 90% within a temperature range of Ar3 to 950°C.

(Cooling Rate of Accelerated Cooling: 30 to 200 °C/s)

[0087] In the accelerated cooling which is performed subsequently after the hot rolling, martensite is formed. The cooling rate of the accelerated cooling is required to be 30 °C/s or higher to increase a martensite area fraction. A sufficient martensite area fraction is not obtained when the cooling rate is lower than 30 °C/s. In order to promote the martensitic transformation, the cooling rate is preferably increased, but there is a restriction caused by a plate thickness or facility. Accordingly, the upper limit may be 200 °C/s or lower. The cooling rate is calculated as follows: a temperature variation of a steel plate surface after hot rolling is measured, and a difference between a surface temperature before the water cooling is started and a surface temperature immediately after the water cooling is stopped is divided by a time required for cooling.

(Accelerated Cooling Stop Temperature: not higher than Mf (°C) and lower than 300°C)

[0088] The inventors conducted studies on the relationship between the hardenability and the accelerated cooling stop temperature, and the microstructure and the total elongation. Here, in a case where a steel plate is rapidly cooled after hot rolling, a martensitic transformation start temperature Ms (°C) is obtained by (Formula 3). A martensitic transformation end temperature Mf (°C) is lower than Ms (°C) by approximately 150°C, and is obtained by (Formula 4). In (Formula 3), each of [C], [Mn], [V], [Cr], [Ni], [Cu], [Mo], and [Al] represents a content (mass%) of each element, and 0 is substituted in a case where the element is not contained.

$$Ms=550-361\times[C]-39\times[Mn]-35\times[V]-20\times[Cr]-17\times[Ni]-10\times[Cu]-5\times[Mo]+30\times[Al] \ldots \text{(Formula 3)}$$

$$Mf=Ms-150 \ldots \text{(Formula 4)}$$

[0089] In order to transform the microstructure to martensite, cooling to at least Ms (°C) or lower is required, and in a case where cooling (rapid cooling) to Mf (°C) or lower is performed, 90% or more of the microstructure transforms to martensite. However, in a case where the cooling stop temperature is 300°C or higher, the cooling may become unstable and a part of the microstructure transforms to not martensite but bainite. Accordingly, the cooling stop temperature is adjusted to be not higher than Mf (°C) and lower than 300°C.

[0090] As described above, the accelerated cooling stop temperature is very important, and a precondition is set that the accelerated cooling is stopped at a temperature lower than the martensitic transformation start temperature Ms (°C). In addition, in a case where the accelerated cooling is performed to a temperature which is not higher than the martensitic transformation completion temperature Mf (°C) and lower than 300°C, the microstructure transforms to a structure mainly including martensite in which the generation of a carbide is suppressed.

[0091] In a case where the accelerated cooling stop temperature is between Ms (°C) and Mf (°C) (between Ms-Mf), the ductility of a high strength steel plate is influenced by hardenability. That is, in a case where the hardenability is increased, the formation of bainite is suppressed, and the generation of a coarse cementite-based carbide is suppressed. Accordingly, the total elongation is improved, and the variation is also reduced.

[0092] The relationship between the accelerated cooling stop temperature Tcf and Mf and the total elongation, and the influence of DI and the C content on the total elongation are qualitatively summarized as schematically shown in FIG. 1. Here, in FIG. 1, the vertical axis represents a total elongation, the horizontal axis represents accelerated cooling stop temperature Tcf, and DI represents a hardenability index which is obtained by (Formula 1).

[0093] As shown in the graph of FIG. 1, in a case where the accelerated cooling stop temperature Tcf is reduced, the martensitic transformation is promoted, and the formation of bainite is suppressed. Accordingly, the total elongation is improved, and in a case where Tcf is not higher than Mf, the total elongation becomes constant. In a case where Tcf is not higher than Mf, the total elongation is almost decided by the C content, and the total elongation is improved by reducing the C content.

[0094] In a case where the accelerated cooling stop temperature Tcf is between Ms and Mf, the total elongation is improved together with a reduction of Tcf. However, in this case, in a case where an alloying element is added to increase hardenability, DI is increased, and thus the formation of bainite is suppressed. Accordingly, the generation of a coarse carbide is suppressed, and thus the total elongation is improved.

[0095] The lower limit of the accelerated cooling stop temperature is not particularly limited, and accelerated cooling may also be performed to room temperature. The accelerated cooling stop temperature is preferably 100°C or higher to increase a yield strength by, for example, the action of locking carbon atoms in the dislocation.

[0096] After the accelerated cooling is stopped, a heat treatment such as tempering is not performed, and air cooling to room temperature is performed.

[Examples]

[0097] Hereinafter, examples of the invention will be described. Conditions in the following examples are an example employed to confirm the feasibility and the effects of the invention, and the invention is not limited to the example. In addition, without departing from the gist of the invention, the invention can employ various conditions as long as the object of the invention is achieved.

[0098] A slab obtained by steel making for chemical components (including a remainder consisting of Fe and impurities) shown in Table 1 was formed into a steel plate having a plate thickness of 4.5 to 20 mm under manufacturing conditions shown in Table 2. The "heating temperature" represents a reheating temperature of the slab, the "rolling end temperature" represents a temperature at which hot rolling is ended, the "water cooling start temperature" represents a surface temperature of the steel plate when accelerated cooling (water cooling) is started, the "cooling rate" represents an average cooling rate in a thickness middle portion within a temperature range of Ar3 (°C) to an accelerated cooling stop temperature, and the "water cooling stop temperature" represents a surface temperature of the steel plate when water cooling is stopped. The surface temperature of the steel plate was measured by a radiation-type thermometer, and the "cooling rate" was calculated by obtaining a temperature of the thickness middle portion from the surface temperature through thermal conductivity calculation. Tempering was not performed on any steel plate.

[0099] The microstructure and the mechanical properties (yield strength, tensile strength, total elongation, toughness, and joint strength) of the obtained steel plate were evaluated.

[0100] The distinguishment of a microstructure and the measurement of a martensite area fraction and a bainite area fraction were performed by the following method.

[0101] A cross-section of a steel plate was subjected to mirror polishing, and then near a 1/4 t-portion in the cross-section parallel to a rolling direction was subjected to nital etching. Two regions within a range of 120 μm×100 μm were photographed at 500-fold magnification using an optical microscope to measure an area fraction of a microstructure in which an acicular lath structure was developed. Regarding the acicular structure, the cross-section of the steel plate was subjected to electrolytic polishing, and then a portion near the 1/4 t-portion in the cross-section of the steel plate was observed by a scanning electron microscope (SEM). Here, the magnification was 5,000 times, and the photographing was performed within a range of 50 μm×40 μm. In a case where a long axis direction of cementite was oriented in two or more directions in the block, the acicular structure was defined as martensite, and an area fraction of the region was obtained. The product of the acicular structure area fraction measured using the optical microscope and the martensite area fraction measured using SEM was an area fraction of the martensite structure of this steel. An acicular structure other than the martensite was determined as bainite.

[0102] In the above-described structure observation using a scanning electron microscope, in a case where it was not possible to clearly distinguish whether or not the long axis direction of cementite is oriented in two or more directions in the block, the area fraction of a microstructure in which an acicular lath structure was developed was defined as the total area fraction of martensite and bainite using an optical microscope.

[0103] The total area fraction of martensite and bainite of 99% or greater, or in a case where it was possible to clearly distinguish the martensite, the martensite area fraction of 90% or greater was set as a target value.

[0104] A microstructure (remainder) other than the "martensite and bainite" described in Table 3 includes one or more of ferrite, pearlite, bainite, and residual austenite.

[0105] Furthermore, a cross-section of the steel plate was subjected to electrolytic polishing, and then a portion near a 1/4 t-portion in the cross-section of the steel plate was observed by a scanning electron microscope (SEM) to measure the number density of cementite. Specifically, a cross-section of the steel plate was subjected to electrolytic polishing, and then a portion near a 1/4 t-portion in the cross-section of the steel plate was photographed within a range of 50 μm×40 μm at 5,000-fold magnification by a scanning electron microscope (SEM). Based on the contrast in the obtained image, the number of precipitates as cementite having an aspect ratio of 2.0 or greater and a length of 0.1 μm or greater in a long axis direction was counted using image analysis software. Similarly, the number of cementite having an aspect ratio of 2.0 or greater and a length of 1.0 μm or greater in a long axis direction was counted. The obtained number of precipitates of 1.0 μm or greater was divided by the number of cementite of 0.1 μm or greater, and thus the number fraction (%) of cementite of 1.0 μm or greater was obtained. In a case where the number fraction of cementite of 1.0 μm or greater was 5% or less, this was judged as a good result.

[0106] The aspect ratio of prior austenite grains was measured. Specifically, near a 1/4 t-portion in a cross-section parallel to a rolling direction was etched with nital, and two regions within a range of 120 μm×100 μm were photographed at 500-fold magnification using an optical microscope. From the obtained image, long axis lengths and short axis lengths of at least 50 prior austenite grains were measured, and the long axis length was divided by the short axis length to obtain an aspect ratio of each grain. An average of the aspect ratios of the prior austenite grains was obtained and defined as an aspect ratio of the prior austenite grains. In a case where the aspect ratio of the prior austenite grains was 2.0 or greater, this was judged as a good result.

[0107] A test piece (overall thickness) was collected from the steel plate, and a tensile strength, a yield strength, and a total elongation were measured based on JIS Z 2241. In addition, a Charpy absorbed energy at -20°C and a Charpy absorbed energy at -40 °C were measured based on JIS Z 2242. The tensile test piece is a No. 5 test piece (overall thickness) collected such that a longitudinal direction is perpendicular to the rolling direction, and the yield strength is 0.2% proof stress. The Charpy test piece is a sub-sized test piece of 10 mm×5 mm collected from a thickness middle portion such that a longitudinal direction is the rolling direction.

[0108] The mechanical properties were evaluated to be good in a case where the yield strength was 885 MPa or greater, the tensile strength was 950 MPa or greater, the total elongation was 12% or greater, and the absorbed energy value at -20°C (vE_{-20}) was 59 J/cm^2 or greater as a result of the tests.

[0109] Welding joints were produced using steel plates having good mechanical properties (steel plate Nos. 1 to 16) and a steel plate No. 32 in which Pcm was less than 0.189%.

[0110] The welding method was MAG welding, and the weld heat input was 7.0 kJ/cm or 10.0 kJ/cm. In a case where the heat input was 7.0 kJ/cm, the welding conditions were set as follows: a current of 280 A, a voltage of 27 V, and a welding rate of 65 cm/min. In a case where the heat input was 10.0 kJ/cm, the welding conditions were set as follows: a current of 305 A, a voltage of 29 V, and a welding rate of 53 cm/min.

[0111] The tensile strength (joint strength) of the welding joint was evaluated by a tensile test specified in JIS Z 3121, and evaluated to be good in a case where the tensile strength was 950 MPa or greater.

[0112] The evaluation results are shown in Table 3. In Table 3, the underlined numerical values indicate that the values are out of the range of the invention, or target properties are not obtained.

[0113] Steel plate Nos. 1 to 16 are invention examples, and an excellent strength, excellent ductility, and excellent toughness are obtained. In addition, the joint strength is 950 MPa or greater. In an example in which Mo/Cr is 0.20 or higher, excellent toughness is obtained even at a test temperature of -40°C.

[0114] Steel plate Nos. 17 to 35 are comparative examples, and one or more of the yield strength, the tensile strength, the total elongation, and vE_{-20} does not satisfy a target value.

[0115] Since each of steel plate Nos. 17, 26, and 29 had a low C or Mn content, the strength thereof was reduced. The fraction of martensite was also insufficient in the steel plate Nos. 26 and 29.

[0116] A steel plate No. 20 had a low Mn content and had low hardenability. Accordingly, ferrite and bainite were formed other than martensite, and thus the amount of martensite formed did not satisfy the range of the invention. As a result, the strength was significantly reduced.

[0117] In each of steel plate Nos. 18, 19, 21, 22, 23, 27, 28, and 30, the C content, the Si content, the Mn content, the Cr content, or the Mo content was too high, and thus ductility and toughness were low.

[0118] In a steel plate No. 24, worked ferrite was formed other than martensite due to a low rolling end temperature and a low water cooling start temperature. Thus, the fraction of martensite did not satisfy the range of the invention, and as a result, the strength was low.

[0119] In a steel plate No. 33, worked ferrite was formed other than martensite due to a low water cooling start temperature. Thus, the fraction of martensite did not satisfy the range of the invention, and as a result, the strength was low.

[0120] In steel plate Nos. 25 and 34, untransformed austenite transformed to bainite due to a high water cooling stop temperature, and thus the fraction of martensite was low. In addition, the total elongation was low due to the excessive generation of voids starting from a coarse carbide (cementite) formed caused by the bainite. In addition, the steel plate No. 34 had a low yield strength.

[0121] A steel plate No. 31 had a high Cr content and a high Mo content, and DI was too high. Accordingly, the toughness and the total elongation were low.

[0122] In a steel plate No. 32, Pcm was low, and thus the joint strength was less than 950 MPa.

[0123] In a steel plate No. 35, the aspect ratio of prior austenite grains was less than 2.0 with a low rolling reduction in a non-recrystallization region. Thus, the toughness was low.

[Table 1]

Steel plate No.	Chemical Components (mass%)																			Cr+Mo	Mo/Cr	DI	Pcm
	C	Si	Mn	P	S	Cr	Mo	Al	Nb	Ti	B	N	Cu	Ni	V	Ca	W	Mg	REM				
1	0.066	0.31	1.44	0.008	0.0020	0.51	0.40	0.045	0.031	0.016	0.0010	0.0032								0.91	0.78	4.3	0.206
2	0.066		1.20	0.006	0.0020	0.61	0.43	0.045	0.041	0.016	0.0009	0.0028								1.04	0.70	3.5	0.190
3	0.065	0.31	1.45	0.008	0.0021	1.00	0.40	0.045	0.029	0.016	0.0009	0.0033								1.40	0.40	6.5	0.229
4	0.076	0.31	1.46	0.007	0.0020	0.50	0.40	0.045	0.028	0.015	0.0010	0.0032						0.0016		0.90	0.80	4.6	0.216
5	0.087	0.30	1.46	0.008	0.0019	0.51	0.40	0.004	0.030	0.028	0.0011	0.0036					0.20			0.91	0.78	4.9	0.228
6	0.074	0.21	1.60	0.008	0.0020	0.89	0.20	0.038	0.021	0.016	0.0010	0.0038			0.006					1.09	0.22	4.8	0.224
7	0.081	0.29	1.42	0.005	0.0010	0.50	0.42	0.034	0.024	0.014	0.0009	0.0038	0.14	0.11		0.0012				0.91	0.84	5.1	0.228
8	0.090	0.30	1.46	0.008	0.0018	0.50	0.35	0.043	0.030	0.015	0.0010	0.0035		0.43						0.85	0.70	5.7	0.234
9	0.071	0.30	1.47	0.008	0.0021	1.71		0.038	0.032	0.016	0.0005	0.0040								1.71	0.00	4.5	0.243
10	0.067	0.28	1.42	0.008	0.0020	0.40	0.64	0.045	0.031	0.016	0.0010	0.0032								1.04	1.60	4.9	0.215
11	0.064	0.36	1.54	0.007	0.0020	0.24	0.80	0.036	0.029	0.014	0.0008	0.0027								1.04	3.33	5.1	0.222
12	0.084	0.29	1.50	0.007	0.0024		0.65	0.045	0.012	0.004	0.0010	0.0032								0.65	>10	3.0	0.217
13	0.090	0.31	1.60	0.007	0.0018	0.55	0.54	0.043	0.029	0.016	0.0011	0.0036							0.0023	1.09	0.98	6.8	0.249
14	0.074	0.10	1.69	0.008	0.0020	0.72	0.56	0.021	0.020	0.016	0.0010	0.0038	0.2							1.28	0.78	7.3	0.251
15	0.091	0.26	1.43	0.005	0.0034		0.52	0.034	0.024	0.014	0.0009	0.0038		0.4						0.52	>10	3.1	0.217
16	0.092	0.46	1.21	0.007	0.0026	0.45	0.52	0.038	0.032	0.016	0.0009	0.0040			0.05	0.001				0.97	1.16	5.1	0.235
17	0.040	0.30	1.45	0.008	0.0020	0.50	0.40	0.045	0.031	0.015	0.0010	0.0035								0.90	0.80	3.3	0.179
18	0.120	0.30	1.45	0.008	0.0020	0.51	0.38	0.042	0.029	0.016	0.0010	0.0036								0.89	0.75	5.6	0.258
19	0.074	0.81	1.42	0.008	0.0020	0.48	0.40	0.045	0.032	0.015	0.0009	0.0034								0.88	0.83	5.5	0.227
20	0.063	0.28	0.50	0.008	0.0020	0.12	0.11	0.042	0.031	0.014	0.0008	0.0032								0.23	0.92	0.6	0.115
21	0.094	0.31	2.45	0.006	0.0018	0.22	0.20	0.030	0.011	0.012	0.0004	0.0030								0.42	0.91	4.1	0.253
22	0.054	0.30	1.20	0.008	0.0021	2.01	0.32	0.038	0.031	0.016	0.0009	0.0040								2.33	0.16	7.6	0.250
23	0.089	0.29	1.44	0.008	0.0020	0.67	1.10	0.045	0.029	0.016	0.0011	0.0035								1.77	1.64	11.4	0.283
24	0.074	0.30	1.44	0.007	0.0019	0.49	0.39	0.043	0.028	0.014	0.0009	0.0033								0.88	0.80	4.4	0.211
25	0.076	0.31	1.46	0.008	0.0020	0.50	0.40	0.045	0.030	0.015	0.0010	0.0032								0.90	0.80	4.6	0.216

26	0.044	0.28	1.70	0.007	0.0030		0.89	0.040	0.020	0.016	0.0010	0.0035								0.89	>10	3.1	0.203
27	0.140	0.24	1.42	0.008	0.0020		0.55	0.042	0.029	0.016	0.0010	0.0036								0.55	>10	3.3	0.261
28	0.074	0.81	1.44	0.008	0.0020		0.62	0.042	0.029	0.016	0.0010	0.0034								0.62	>10	3.4	0.219
29	0.065	0.31	0.92	0.007	0.0019	0.60	0.52	0.042	0.031	0.014	0.0008	0.0032								1.12	0.87	3.8	0.190
30	0.084	0.30	2.30	0.006	0.0030	0.22	0.51	0.030	0.030	0.020	0.0010	0.0030								0.73	2.32	5.8	0.259
31	0.071	0.30	1.47	0.008	0.0021	1.71	0.53	0.038	0.031	0.016	0.0009	0.0040								2.24	0.31	12.1	0.280
32	0.066	0.24	1.45	0.008	0.0020		0.51	0.046	0.010	0.017	0.0008	0.0032								0.51	>10	2.2	0.185
33	0.075	0.30	1.46	0.008	0.0024	0.49	0.51	0.043	0.028	0.014	0.0009	0.0033								1.00	1.04	5.2	0.221
34	0.080	0.31	1.40	0.008	0.0021	0.20	0.53	0.045	0.030	0.015	0.0010	0.0032								0.73	2.65	3.6	0.211
35	0.074	0.20	1.52	0.006	0.0017	1.16	0.40	0.030	0.024	0.013	0.0012	0.0028		0.45						0.56	2.50	3.5	0.205

The blanks mean that the alloying elements are not added intentionally.

The underlines mean that the values are out of the range of the invention.

[Table 2]

Steel plate No.	Ar3 °C	Ms °C	Mf °C	Heating Temperature °C	Rolling End Temperature °C	Water Cooling Start Temperature °C	Cooling Rate °C/s	Water Cooling Stop Temperature °C
1	727	459	309	1230	860	770	97	284
2	732	466	316	1230	859	765	108	234
3	715	449	299	1230	859	773	95	217
4	722	455	305	1230	859	760	97	265
5	717	450	300	1230	860	787	87	281
6	707	443	293	1230	860	803	149	190
7	715	451	301	1230	912	730	140	230
8	702	443	293	1230	860	792	117	272
9	705	434	284	1230	860	805	130	281
10	723	461	311	1230	860	769	106	294
11	717	459	309	1230	859	764	105	246
12	720	459	309	1230	859	750	97	270
13	701	443	293	1230	860	768	84	282
14	687	439	289	1230	860	793	79	276
15	711	453	303	1230	924	810	124	281
16	734	457	307	1230	860	756	90	273
17	737	468	318	1230	855	790	112	295
18	705	439	289	1230	860	730	103	132
19	738	458	308	1230	860	804	113	307
20	810	506	356	1230	857	821	104	256
21	660	416	266	1230	843	752	98	201
22	713	443	293	1230	824	764	97	224
23	693	444	294	1230	846	734	104	189
24	724	457	307	1230	700	662	112	123
25	722	455	305	1230	859	765	104	393
26	715	465	315	1230	855	790	103	291
27	705	443	293	1230	860	742	97	140
28	742	465	315	1230	860	815	122	278
29	757	477	327	1230	885	780	94	289
30	665	424	274	1230	836	790	98	242
31	689	431	281	1230	860	805	130	270
32	734	468	318	1230	846	741	89	290
33	719	455	305	1230	720	640	96	143
34	728	461	311	1230	846	768	94	435
35	708	452	302	1230	1000	900	98	210

[Table 3]

Steel plate No.	Plate thickness (mm)	Martensite +Bainite %	Martensite %	Aspect Ratio of Prior Austenite Grains	Number Fraction of Cementite of 1 μm or Greater %	Yield Strength MPa	Tensile Strength MPa	Total elongation %	vE_{-20} J/cm^2	vE_{-40} J/cm^2	Weld Heat Input kJ/cm	Joint Strength MPa	Remarks
1	8	100	-	3.6	3	895	1072	14	331	255	10.0	1015	Invention Examples
2	8	100	94	3.7	1	895	1070	15	270	250	7.0	960	
3	8	100	95	4.0	0	895	1133	15	270	232	10.0	1135	
4	8	100	-	3.5	2	986	1145	14	293	252	10.0	1089	
5	8	100	92	3.0	1	991	1183	13	243	76	10.0	1160	
6	6	100	96	2.8	0	937	1140	13	233	87	10.0	1134	
7	20	99	93	4.0	0	1040	1214	15	268	85	10.0	1156	
8	8	100	98	3.8	1	992	1174	13	223	77	10.0	1184	
9	8	100	-	4.0	2	919	1131	13	90	11	10.0	1146	
10	4.5	100	91	2.8	1	921	1053	15	246	155	7.0	1052	
11	8	99	92	4.1	0	905	1034	15	230	219	10.0	1051	
12	8	100	92	3.6	1	1010	1250	13	209	130	10.0	1096	
13	8	100	94	2.8	1	987	1240	14	193	114	10.0	1251	
14	8	100	93	4.1	1	984	1184	14	230	205	10.0	1194	
15	8	99	91	4.0	0	1014	1254	14	168	98	10.0	1096	
16	8	100	92	3.5	0	1025	1264	13	120	95	10.0	1183	
17	8	100	-	3.5	1	823	1002	18	323	261		-	Comparative Example
18	8	100	98	3.2	2	1010	1279	11	55	44		-	
19	8	100	-	3.8	2	961	1097	11	56	43		-	
20	8	74	64	4.0	29	731	912	21	343	255		-	
21	6	99	-	3.5	1	981	1153	11	32	6		-	
22	6	100	91	4.3	0	896	1076	11	46	13		-	

(continued)

Steel plate No.	Plate thickness (mm)	Martensite +Bainite %	Martensite %	Aspect Ratio of Prior Austenite Grains	Number Fraction of Cementite of 1 μm or Greater %	Yield Strength MPa	Tensile Strength MPa	Total elongation %	vE_{-20} J/cm^2	vE_{-40} J/cm^2	Weld Heat Input kJ/cm	Joint Strength MPa	Remarks
23	6	100	91	2.9	0	997	1209	$\underline{11}$	$\underline{58}$	46		-	
24	8	$\underline{82}$	72	2.3	$\underline{30}$	$\underline{778}$	$\underline{901}$	15	280	246		-	
25	8	$\underline{91}$	-	3.3	$\underline{9}$	889	1014	$\underline{9}$	270	216		-	
26	8	$\underline{86}$	-	4.0	$\underline{26}$	$\underline{783}$	$\underline{940}$	18	338	330		-	
27	8	100	98	3.8	3	1045	1359	$\underline{10}$	$\underline{43}$	13		-	
28	8	100	-	3.0	2	896	1122	$\underline{11}$	$\underline{42}$	14		-	
29	8	$\underline{82}$	72	2.8	$\underline{34}$	$\underline{745}$	$\underline{945}$	14	330	209		-	
30	8	99	-	4.0	1	941	1201	$\underline{11}$	$\underline{34}$	8		-	
31	8	100	91	2.9	1	991	1203	$\underline{11}$	$\underline{45}$	11		-	
32	8	100	91	3.9	1	887	984	14	248	193	7.0	$\underline{927}$	
33	8	$\underline{78}$	68	2.2	$\underline{32}$	$\underline{764}$	$\underline{894}$	16	334	293		-	
34	8	$\underline{92}$	-	3.6	$\underline{11}$	$\underline{867}$	1004	10	309	234		-	
35	8	100	93	$\underline{1.4}$	3	921	1186	13	$\underline{46}$	16		-	

The underlines mean that the values are out of the range of the invention, or target properties are not obtained.

[Industrial Applicability]

[0124] According to the invention, it is possible to provide a high strength steel plate which has a yield strength of 885 MPa or greater, a tensile strength of 950 MPa or greater, and a total elongation of 12% or greater without containing a large amount of expensive alloying elements. In addition, this steel plate exhibits excellent toughness such that a Charpy absorbed energy at -20°C is 59 J/cm^2 or greater. Accordingly, the invention is useful for industry.

Claims

1. A high strength steel plate consisting of, as a chemical composition, by mass%:

C: 0.050% to 0.100%,
Si: 0% to 0.50%,
Mn: 1.20% to 1.70%,
P: 0.020% or less,
S: 0.0050% or less,
N: 0% to 0.0080%,
B: 0.0003% to 0.0030%,
Ti: 0.003% to 0.030%,
Nb: 0.003% to 0.050%,
Cr: 0% to 2.00%,
Mo: 0% to 0.90%,
Al: 0% to 0.100%,
Cu: 0% to 0.50%,
Ni: 0% to 0.50%,
V: 0% to 0.100%,
W: 0% to 0.50%,
Ca: 0% to 0.0030%,
Mg: 0% to 0.0030%,
REM: 0% to 0.0030%, and
a remainder consisting of Fe and impurities,

wherein one or both of Cr and Mo is contained in an amount of 0.20% or greater in total, and the Cr content is 0.80% or less in a case where the Mo content is greater than 0.50%,
DI which is obtained by the Formula 1 is 2.0 to 7.8,
Pcm which is obtained by the Formula 2 is 0.189% or greater,
a microstructure includes one or both of martensite and bainite such that a total area fraction thereof is 99% or greater,
an aspect ratio of prior austenite grains is 2.0 or greater,
a number fraction of cementite having a length of 1.0 μm or greater in a long axis direction with respect to cementite having a length of 0.1 μm or greater in the long axis direction is 5% or less,
a plate thickness is 4.5 mm to 20 mm, and
a yield strength is 885 MPa or greater, a tensile strength is 950 MPa or greater, a total elongation is 12% or greater, and a Charpy absorbed energy at -20°C is 59 J/cm^2,

$$DI=[C]^{0.5}\times\{0.34\times(1+0.64\times[Si])\times(1+4.1\times[Mn])\times(1+0.27\times[Cu])\times(1+0.52\times[Ni])\times(1+2.33\times[Cr])\times(1+3.14\times[Mo])\}\times1.2 \ldots \text{(Formula 1)}$$

$$Pcm=[C]+[Si]/30+[Mn]/20+[Cu]/20+[Ni]/60+[Cr]/20+[Mo]/15+[V]/10+5\times[B] \ldots \text{(Formula 2)}$$

in the Formulae 1 and 2, each of [C], [Si], [Mn], [Cu], [Ni], [Cr], [Mo], [V], and [B] represents a content of each element by mass%, and 0 is substituted in a case where the element is not contained.

2. The high strength steel plate according to claim 1, wherein the microstructure includes 90% or greater of martensite in terms of area fraction.

3. The high strength steel plate according to claim 1 or 2, wherein the chemical composition includes Cu: 0% to 0.25% by mass%.

4. The high strength steel plate according to any one of claims 1 to 3, wherein the chemical composition includes Ni: 0% to 0.25% by mass%.

5. The high strength steel plate according to any one of claims 1 to 4, wherein the chemical composition includes V: 0% to 0.050% by mass%.

6. The high strength steel plate according to any one of claims 1 to 5, wherein the chemical composition includes W: 0% to 0.05% by mass%.

7. The high strength steel plate according to any one of claims 1 to 6, wherein the plate thickness is 4.5 mm to 15 mm.

8. The high strength steel plate according to any one of claims 1 to 7, wherein in a case where the Mo content is represented by [Mo] and the Cr content is represented by [Cr], [Mo]/[Cr] is 0.20 or greater.

9. The high strength steel plate according to claim 8, wherein a Charpy absorbed energy at -40°C is 59 J/cm^2 or greater.

10. The high strength steel plate according to any one of claims 1 to 9, wherein the Pcm is 0.196% or greater.

FIG. 1

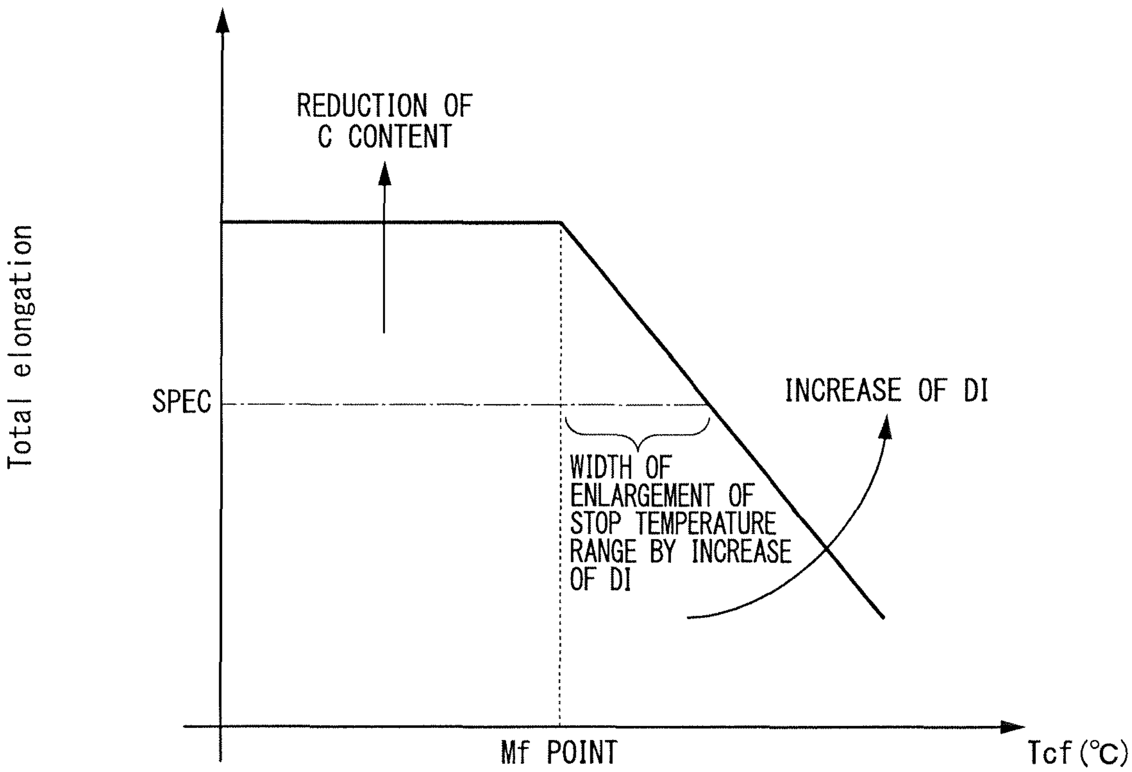

REDUCTION OF
C CONTENT
Total elongation
SPEC
INCREASE OF DI
WIDTH OF
ENLARGEMENT OF
STOP TEMPERATURE
RANGE BY INCREASE
OF DI
Mf POINT
Tcf (℃)

FIG. 2

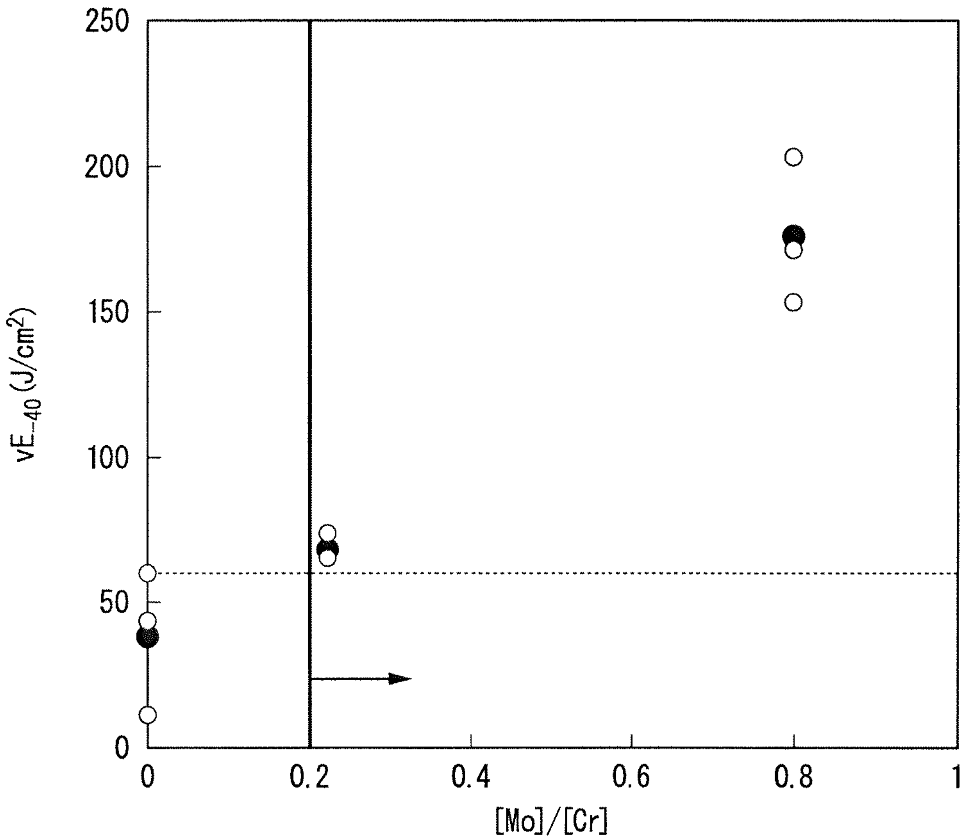


FIG. 3

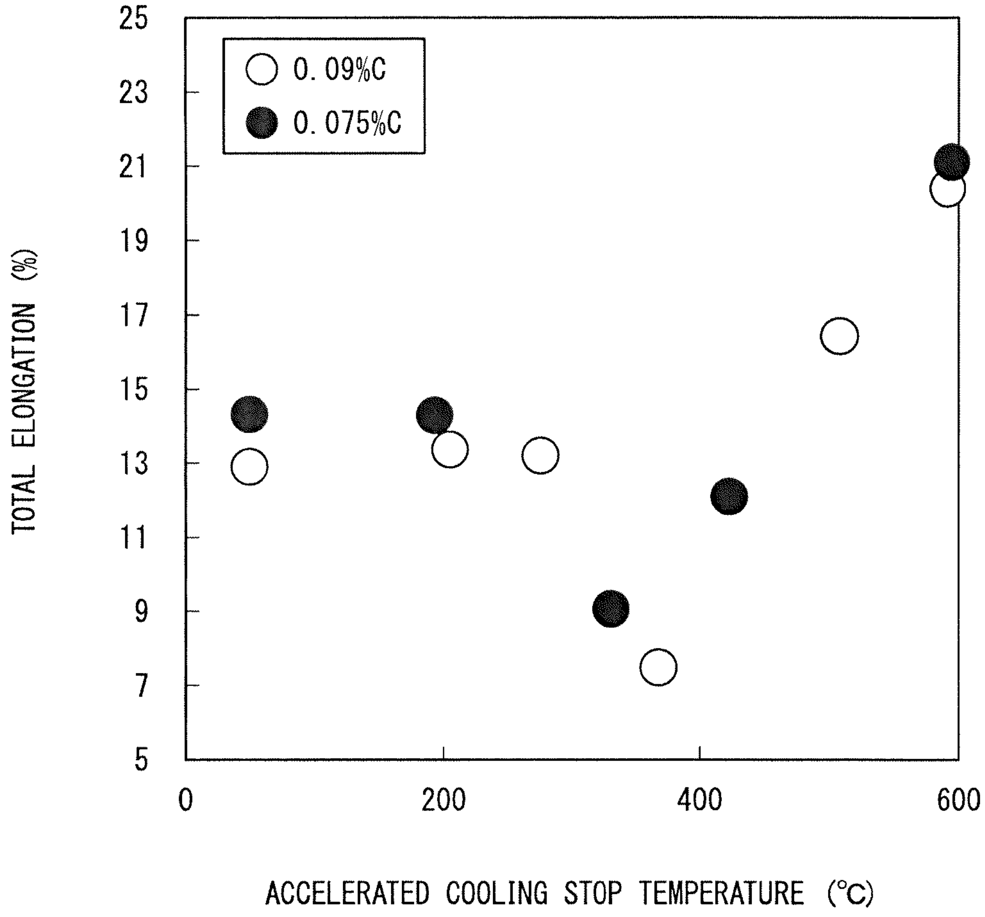

0. 09%C
0. 075%C
TOTAL ELONGATION (%)
25
23
21
19
17
15
13
11
9
7
5
0
200
400
600
ACCELERATED COOLING STOP TEMPERATURE (°C)

FIG. 4A

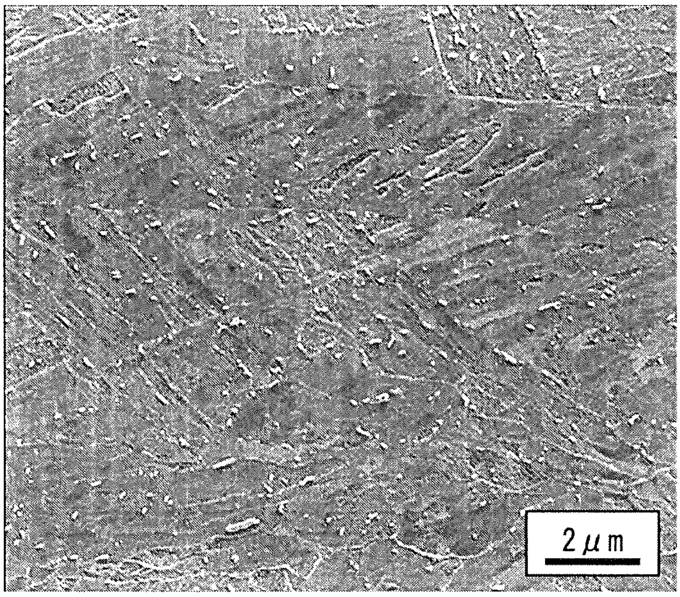


FIG. 4B

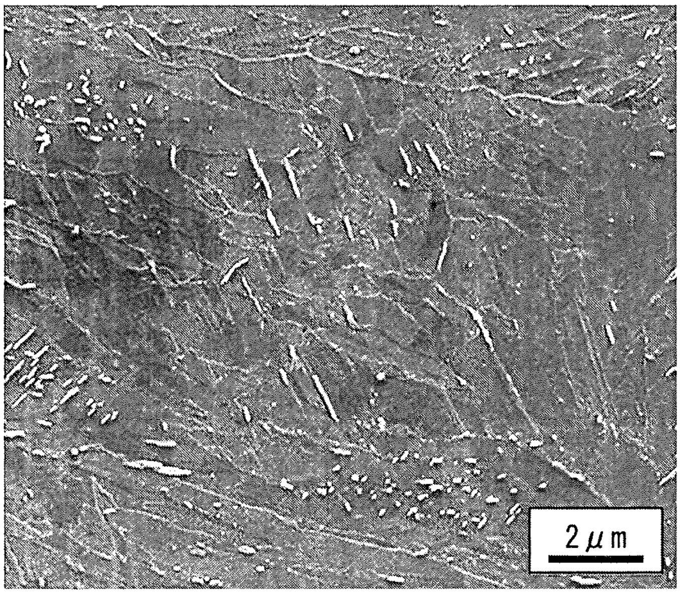
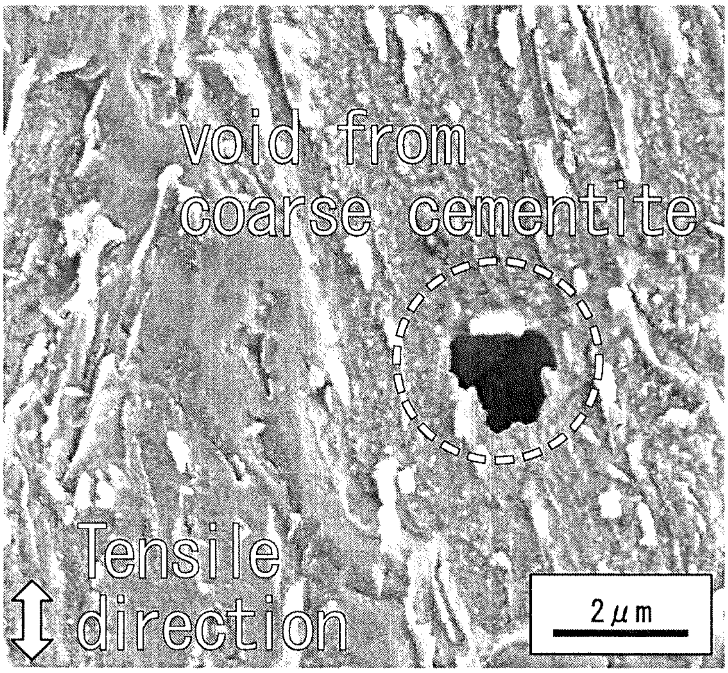


FIG. 5



INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2016/072316

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C21D8/02*(2006.01)i, *C22C38/14*(2006.01)i, *C22C38/58* (2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00, C21D8/02, C22C38/14, C22C38/58

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2016
Kokai Jitsuyo Shinan Koho	1971-2016	Toroku Jitsuyo Shinan Koho	1994-2016

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	JP 2014-529686 A (Baoshan Iron & Steel Co., Ltd.), 13 November 2014 (13.11.2014), claims; paragraphs [0009], [0019], [0023] to [0038]; examples; tables 1 to 3 & US 2015/0211098 A1 claims; paragraphs [0010], [0020], [0025] to [0039]; examples; tables 1 to 3 & WO 2014/019352 A1 & EP 2881486 A1 & CN 102747280 A & KR 10-2015-0034580 A	1-7,9-10 8
Y A	JP 2011-52321 A (JFE Steel Corp.), 17 March 2011 (17.03.2011), claims; paragraphs [0034], [0035]; examples (Family: none)	1-7,9-10 8

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

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Date of the actual completion of the international search	Date of mailing of the international search report
23 August 2016 (23.08.16)	06 September 2016 (06.09.16)

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3,Kasumigaseki,Chiyoda-ku, Tokyo 100-8915,Japan	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	WO 2012/060405 A1 (Nippon Steel Corp.), 10 May 2012 (10.05.2012), claims; paragraphs [0044], [0045]; examples & JP 5037744 B2 & EP 2612945 A1 claims; paragraphs [0041], [0042]; examples & KR 10-2013-0051518 A & CN 103189537 A & TW 201226582 A	1-7,9-10 8
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A	JP 2014-47414 A (Nippon Steel & Sumitomo Metal Corp.), 17 March 2014 (17.03.2014), (Family: none)	1-10
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A	JP 2010-70845 A (Korea Institute of Machinery & Materials), 02 April 2010 (02.04.2010), & KR 10-2010-0032490 A & CN 101676430 A	1-10

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