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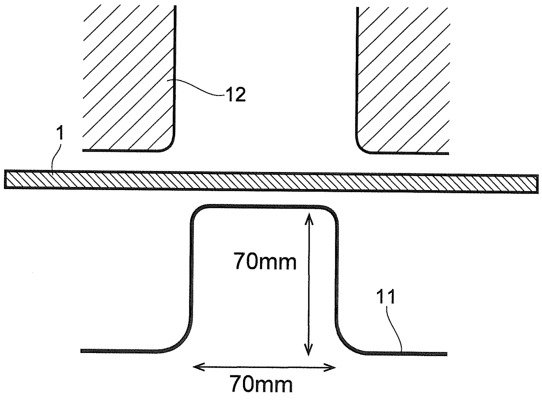
(54) HOT-ROLLED STEEL PLATE MEMBER

(57) A hot-formed steel sheet member having a chemical composition, consisting of, in terms of mass %, from 0.08 to 0.16% of C, 0.19% or less of Si, from 0.40 to 1.50% of Mn, 0.02% or less of P, 0.01% or less of S, from 0.01 to 1.0% of sol. Al, 0.01% or less of N, from 0.25 to 3.00% of Cr, from 0.01 to 0.05% of Ti, from 0.001 to 0.01% of B, from 0 to 0.50% of Nb, from 0 to 2.0% of Ni, from 0 to 1.0% of Cu, from 0 to 1.0% of Mo, from 0 to 1.0% of V, from 0 to 0.005% of Ca, and a reminder consisting of Fe and impurities, wherein a total volume fraction of martensite, tempered martensite, and bainite is 50% or more, and a volume fraction of ferrite is 3% or less, an average grain size of prior γ grains is 10 μm or less, and a number density of residual carbides which are present is 4×10^3 per mm^2 or less.

FIG.1



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Description

Technical Field

[0001] The present specification relates to a hot-formed steel sheet member formed by hot-forming a steel sheet.

Background Art

[0002] A high-strength steel sheet having high tensile strength has been widely applied to the field of an automotive steel sheet in order to achieve both weight saving for an improvement in fuel consumption and an improvement in collision resistance. However, the high strength causes deterioration in the press formability of the steel sheet, which makes it difficult to produce products having complicated shapes.

[0003] As a result, for example, the high strength of the steel sheet disadvantageously causes deterioration in ductility, which causes breaking at a site having a high degree of processing, and disadvantageously causes deterioration in dimension accuracy or the like because of increased spring back and wall warpage. Therefore, a steel sheet having high strength, particularly tensile strength of 780 MPa or more, is not easily press-formed to a product having a complicated shape.

[0004] Then, recent years, for example, as disclosed in Japanese Patent Application Laid-Open (JP-A) No. 2002-102980, a hot stamp technique is adopted as a technique for press-forming a material which is hard to form such as a high-strength steel sheet. The hot stamp technique is a hot forming technique for heating and forming a material provided for forming. Since the steel sheet is formed and quenched at the same time in the technique, the steel sheet is soft and has favorable formability during forming, and the formed member after forming can have strength higher than that of a steel sheet for cold forming.

[0005] Japanese Patent Application Laid-Open (JP-A) No. 2006-213959 discloses a steel member having tensile strength of 980 MPa.

[0006] Japanese Patent Application Laid-Open (JP-A) No. 2007-314817 discloses that a hot pressed steel sheet member having excellent tensile strength and toughness is obtained by decreasing a cleanliness level and segregation degrees of P and S.

SUMMARY OF DISCLOSURE

[0007] The metal material described in JP-A No. 2002-102980 has insufficient hardenability during hot press, as a result of which the metal material has poor hardness stability. The steel sheets having excellent tensile strength and toughness are disclosed in JP-A No. 2006-213959 and JP-ANo. 2007-314817, but room for an improvement in local deformation characteristics is left.

[0008] An objective of embodiments of the specification is to provide a hot-formed steel sheet member having excellent hardness stability and local deformability In many cases, a steel sheet member which is hot-formed is not a flat sheet but a formed body, and is referred to as "a hot-formed steel sheet member" including a case in which the hot-formed steel sheet member is the formed body in the specification.

[0009] According to one aspect of the present specification, there is provided a hot-formed steel sheet member having a chemical composition consisting of, in terms of mass %, from 0.08 to 0.16% of C, 0.19% or less of Si, from 0.40 to 1.50% of Mn, 0.02% or less of P, 0.01% or less of S, from 0.01 to 1.0% of sol. Al, 0.01% or less of N, from 0.25 to 3.00% of Cr, from 0.01 to 0.05% of Ti, from 0.001 to 0.01% of B, from 0 to 0.50% of Nb, from 0 to 2.0% of Ni, from 0 to 1.0% of Cu, from 0 to 1.0% of Mo, from 0 to 1.0% of V, from 0 to 0.005% of Ca, and a remainder consisting of Fe and impurities, wherein a total volume fraction of martensite, tempered martensite, and bainite is 50% or more, and a volume fraction of ferrite is 3% or less,
an average grain size of prior γ grains is 10 μm or less, and
a number density of residual carbides which are present is 4×10^3 per mm^2 or less.

BRIEF DESCRIPTION OF DRAWINGS

[0010]

Fig. 1 is a schematic view showing a shape of a mold in hat forming in Examples.
Fig. 2 is a schematic view showing a shape of a formed body obtained by hot-forming in Examples.
Fig. 3 is a schematic view showing a shape of a notch tensile test piece in Examples.

DESCRIPTION OF EMBODIMENTS

[0011] The present inventors have conducted studies earnestly to provide a hot-formed steel sheet member having excellent hardness stability and local deformability, and resultantly obtained the findings described below.

[0012]

(1) Fine prior γ grains in the hot-formed steel sheet member delay the occurrence and connection of voids, which provides an improvement in local deformability. Therefore, the fine prior γ grains are preferable.
(2) In a case in which a number of residual carbides are present in the hot-formed steel sheet member, hardenability after hot-forming may be deteriorated to cause deterioration in hardness stability, and the residual carbides serve as the occurrence source of voids to cause deterioration in the local deformability. Therefore, the number density of the residual carbides is preferably reduced.

[0013] Embodiments of the specification is based on the findings. According to one aspect of the embodiments,

(1) there is provided a hot-formed steel sheet member having a chemical composition, consisting of, in terms of mass %, from 0.08 to 0.16% of C, 0.19% or less of Si, from 0.40 to 1.50% of Mn, 0.02% or less of P, 0.01% or less of S, from 0.01 to 1.0% of sol. Al, 0.01% or less of N, from 0.25 to 3.00% of Cr, from 0.01 to 0.05% of Ti, from 0.001 to 0.01% of B, from 0 to 0.50% of Nb, from 0 to 2.0% of Ni, from 0 to 1.0% of Cu, from 0 to 1.0% of Mo, from 0 to 1.0% of V, from 0 to 0.005% of Ca, and a remainder consisting of Fe and impurities,
wherein a total volume fraction of martensite, tempered martensite, and bainite is 50% or more, and a volume fraction of ferrite is 3% or less,
an average grain size of prior γ grains is 10 μm or less, and
a number density of residual carbides which are present is 4×10^3 per mm^2 or less.
(2) In the hot-formed steel sheet member of (1), the chemical composition preferably includes one or more selected from the group consisting of, in terms of mass %, from 0.003 to 0.50% of Nb, from 0.01 to 2.0% of Ni, from 0.01 to 1.0% of Cu, from 0.01 to 1.0% of Mo, from 0.01 to 1.0% of V, and from 0.001 to 0.005% of Ca.
(3) In the hot-formed steel sheet member of (1) or (2), a value of a cleanliness level of steel specified by JIS G 0555 (2003) is preferably 0.08% or less.
(4) In any one of the hot-formed steel sheet members of (1) to (3), a segregation degree α of Mn represented by the following formula (i) is preferably 1.6 or less,

$$\alpha = [\text{maximum Mn concentration (mass \%) at a central part of a sheet thickness}]/[\text{average Mn concentration (mass \%) at a 1/4 depth position of the sheet thickness from a surface}] \ldots \text{(i)}.$$

(5) In any one of the hot-formed steel sheet members of (1) to (4), the steel sheet member preferably has a surface on which a plating layer is formed.
(6) In any one of the hot-formed steel sheet members of (1) to (5), the steel sheet member preferably has a tensile strength of 1.0 GPa or more.

[0014] Hereinafter, the embodiments will be described in detail.

(A) Chemical Composition

[0015] The reason why the content of each element is limited will be described below. In the description below, the symbol "%" of the content of each element means "mass %".

C: from 0.08 to 0.16%

[0016] C is an element important for improving the hardenability of steel and for securing the strength after quenching. Since C is an austenite-forming element, it has a function to suppress strain-induced ferrite transformation during high strain formation. This makes it easy to obtain a stable hardness distribution in a steel sheet member after hot-forming. The C content of less than 0.08% makes it difficult to secure tensile strength of 1.0 GPa or more after quenching and to obtain the above-mentioned effect. Therefore, the C content is set to 0.08% or more. The C content exceeding 0.16% causes an excessive increase in the strength after quenching to cause deterioration in local deformability. Therefore, the C content is set to 0.16% or less. The C content is preferably 0.085% or more, and more preferably 0.9% or more. The C content is preferably 0.15% or less, and more preferably 0.14% or less.

Si: 0.19% or less

[0017] Si is an element having a function to suppress scale formation during high temperature heating for hot-forming. However, the Si content exceeding 0.19% causes a remarkable increase in a heating temperature required for austenite transformation during hot-forming. This causes an increase in cost required for a heat treatment, and insufficient quenching due to insufficient heating. Si is a ferrite-forming element. Thereby, a too high Si content is apt to produce strain-induced ferrite transformation during high strain formation. This causes a local decrease in the hardness of the steel sheet member after hot-forming, which makes it difficult to obtain a stable hardness distribution. Furthermore, a significant amount of Si causes deterioration in wettability in a case in which a hot-dip plating treatment is performed, which may cause non-plating. Therefore, the Si content is set to 0.19% or less. The Si content is preferably 0.15% or less. In a case in which the above-mentioned effect is desired to be obtained, the Si content is preferably 0.01 % or more.

Mn: from 0.40 to 1.50%

[0018] Mn is an element useful for improving the hardenability of a steel sheet and for stably securing the strength after hot-forming. The Mn content of less than 0.40% makes it difficult to obtain the above-mentioned effect. Therefore, the Mn content is set to 0.40% or more. The Mn content exceeding 1.50% produces coarse MnS, which becomes a factor for deterioration in local deformability. Therefore, the Mn content is set to 1.50% or less. The Mn content is preferably 0.80% or more, and preferably 1.40% or less.

P: 0.02% or less

[0019] Since P is an element contained as impurities, and has functions to make it possible to improve the hardenability of steel and to stably secure the strength of the steel after quenching, P may be positively contained. However, the P content exceeding 0.02% causes remarkable deterioration in local deformability. Therefore, the P content is set to 0.02% or less. The P content is preferably 0.01% or less. Although the lower limit of the P content is not particularly limited, an excessive reduction in the P content causes a remarkable increase in cost. For this reason, the P content is preferably set to 0.0002% or more.

S: 0.01% or less

[0020] S is an element contained as impurities, and causing deterioration in local deformability. The S content exceeding 0.01% causes remarkable deterioration in the local deformability. Therefore, the S content is set to 0.01% or less. Although the lower limit of the S content is not particularly limited, an excessive reduction in the S content causes a remarkable increase in cost. Therefore, the S content is preferably set to 0.0002% or more.

sol. Al: from 0.01 to 1.0%

[0021] sol. Al is an element having a function to enable soundness of steel by deoxidizing molten steel. The sol. Al content of less than 0.01% causes insufficient deoxidation. Furthermore, since the sol. Al is also an element having functions to improve the hardenability of a steel sheet and to stably secure the strength after quenching, the sol. Al may be positively contained. Therefore, the sol. Al content is set to 0.01% or more. However, the sol. Al content exceeding 1.0% provides a small effect obtained by the function, and unnecessarily causes an increase in cost. For this reason, the sol. Al content is set to 1.0% or less. The sol. Al content is preferably 0.02% or more and preferably 0.2% or less.

N: 0.01 % or less

[0022] N is an element contained as impurities, and causing deterioration in toughness. The N content exceeding 0.01 % forms coarse nitride in steel, which causes remarkable deteriorations in local deformability and toughness. Therefore, the N content is set to 0.01% or less. The N content is preferably 0.008% or less. Although the lower limit of the N content need not be particularly limited, an excessive reduction in the N content causes a remarkable increase in cost. For this reason, the N content is preferably set to 0.0002% or more, and more preferably 0.0008% or more.

Cr: from 0.25 to 3.00%

[0023] Cr is an element having a function to improve the hardenability of steel. Therefore, Cr is a particularly important element in an embodiment in which the Mn content is limited to 1.50% or less. Cr is an austenite-forming element, and has a function to suppress strain-induced ferrite transformation during high strain formation. Therefore, Cr is contained, which makes it easy to obtain a stable hardness distribution in a steel sheet member after hot-forming. The Cr content of less than 0.25% cannot sufficiently provide the above-mentioned effect. Therefore, the Cr content is set to 0.25% or more. The Cr content exceeding 3.00% causes Cr to be incrassated in carbonates in carbonates in the steel, which delays the solid solution of the carbides in a heating step in the case of being provided for hot-forming to cause deterioration in the hardenability. Therefore, the Cr content is set to 3.00% or less. The Cr content is preferably 0.30% or more, and more preferably 0.40% or more. The Cr content is preferably 2.50% or less, and more preferably 2.00% or less.

Ti: from 0.01 to 0.05%

[0024] Ti is an element having a function to suppress the recrystallization of austenite grains in a case in which a steel sheet for hot-forming is heated to an Ac_3 point or more and provided for hot-forming. Furthermore, Ti has a function to form fine carbides to suppress the grain growth of the austenite grains, thereby providing fine grains. For this reason, Ti has a function to largely improve the local deformability of a hot-formed steel sheet member. Since Ti is preferentially bonded to N in steel, Ti suppresses the consumption of B due to the precipitation of BN, as a result of which Ti has a function to improve hardenability due to B. Therefore, the Ti content is set to 0.01% or more. However, the Ti content exceeding 0.05% causes an increase in the amount of precipitation of TiC, which causes the consumption of C, thereby causing a decrease in the strength after quenching. For this reason, the Ti content is set to 0.05% or less. The Ti content is preferably 0.015% or more. The Ti content is preferably 0.04% or less, and more preferably 0.03% or less.

B: from 0.001 to 0.01%

[0025] B is an element having functions to makes it possible to improve the hardenability of steel and to stably secure the strength after quenching. Therefore, in an embodiment in which the Mn content is limited to 1.50% or less, B is a particularly important element. The B content of less than 0.001% cannot sufficiently provide the above-mentioned effect. Therefore, the B content is set to 0.001% or more. The B content exceeding 0.01% causes the saturation of the above-mentioned effect, and deterioration in the local deformability of a quenched part. Therefore, the B content is set to 0.01 % or less. The B content is preferably 0.005% or less.

[0026] The hot-formed steel sheet members of the embodiments have a chemical composition consisting of the elements of C to B and the remainder consisting of Fe and impurities.

[0027] The "impurities" herein are elements which are mixed in by various factors in raw materials such as ore or scrap and in a production process when a steel sheet is produced on an industrial scale, and are allowed to be contained within the range such that the elements do not exert an adverse influence on the embodiments.

[0028] The hot-formed steel sheet member of the embodiments may further contain one or more elements selected from the group consisting of Nb, Ni, Cu, Mo, V, and Ca in amounts to be described below in addition to the above-mentioned elements.

Nb: from 0 to 0.50%

[0029] Nb is an element having functions to suppress recrystallization in a case in which a steel sheet for hot-forming is heated to an Ac_3 point or more and provided for hot-forming, and to form fine carbides to suppress the grain growth, thereby providing fine austenite grains. For this reason, Nb has a function to largely improve the local deformability of a hot-formed steel sheet member. Therefore, Nb may be contained if necessary. However, the Nb content exceeding 0.50% causes an increase in the amount of precipitation of NbC to cause the consumption of C, thereby causing a decrease in the strength after quenching. For this reason, the Nb content is set to 0.50% or less. The Nb content is preferably 0.45% or less. In a case in which the above-mentioned effect is desired to be obtained, the Nb content is preferably set to 0.003% or more, and more preferably 0.005% or more.

Ni: from 0 to 2.0%

[0030] Since Ni is an element effective in improving the hardenability of steel sheet and in stably securing the strength after quenching, Ni may be contained if necessary. However, the Ni content exceeding 2.0% provides a small effect, which unnecessarily causes an increase in cost. For this reason, the Ni content is set to 2.0% or less. The Ni content is preferably 1.5% or less. In a case in which the above-mentioned effect is desired to be obtained, the Ni content is preferably set to 0.01% or more, and more preferably 0.05% or more.

Cu: from 0 to 1.0%

[0031] Since Cu is an element effective in improving the hardenability of steel sheet and in stably securing the strength after quenching, Cu may be contained if necessary. However, the Cu content exceeding 1.0% provides a small effect, which unnecessarily causes an increase in cost. For this reason, the Cu content is set to 1.0% or less. The Cu content is preferably 0.5% or less. In a case in which the above-mentioned effect is desired to be obtained, the Cu content is preferably set to 0.01% or more, and more preferably 0.03% or more.

Mo: from 0 to 1.0%

[0032] Mo is an element having a function to form fine carbides in a case in which a steel sheet for hot-forming is heated to an Ac_3 point or more and provided for hot-forming to suppress the grain growth, thereby providing fine austenite grains. Mo has also an effect of largely improving the local deformability of a hot-formed steel sheet member. For these reasons, Mo may be contained if necessary. However, the Mo content exceeding 1.0% causes the saturation of the effect, which unnecessarily causes an increase in cost. Therefore, the Mo content is set to 1.0% or less. The Mo content is preferably 0.7% or less. In a case in which the above-mentioned effect is desired to be obtained, the Mo content is preferably set to 0.01% or more, and more preferably 0.04% or more.

V: from 0 to 1.0%

[0033] Since V is an element effective in improving the hardenability of steel sheet and in stably securing the strength after quenching, V may be contained if necessary. However, the V content exceeding 1.0% provides a small effect, which unnecessarily causes an increase in cost. For this reason, the V content is set to 1.0% or less. The V content is preferably 0.08% or less. In a case in which the effect is desired to be obtained, the V content is preferably set to 0.01% or more, and more preferably 0.02% or more.

Ca: from 0 to 0.005%

[0034] Since Ca is an element having an effect of grain refining of inclusions in steel to improve the local deformability after quenching, Ca may be contained if necessary. However, the Ca content exceeding 0.005% causes the saturation of the effect, which unnecessarily causes an increase in cost. Therefore, the Ca content is set to 0.005% or less. The Ca content is preferably 0.004% or less. In a case in which the effect is desired to be obtained, the Ca content is preferably set to 0.001% or more, and more preferably 0.002% or more.

(B) Metal Structure

[0035] In the embodiments, in order to improve local deformability, variations in hardness in the metal structure after hot-forming is preferably suppressed. Since an increased hardness difference in the structure serves as the starting point of voids, the mixture of a low-temperature transformation structure such as hard martensite or bainite and a soft ferrite structure is preferably suppressed as much as possible. Therefore, it is preferable that the hot-formed steel sheet members of the embodiments mainly have a low-temperature transformation structure, and has a metal structure having a ferrite volume fraction of 3% or less.

[0036] The metal structure mainly having a low-temperature transformation structure means a metal structure in which the total volume fraction of martensite, tempered martensite, and bainite is 50% or more. The tempered martensite herein means martensite transformed during quenching and tempered by automatic tempering, and martensite subjected to low temperature tempering such as a coating baking process after quenching. The volume fraction of the low-temperature transformed structure in the metal structure is preferably 80% or more, and more preferably 90% or more.

[0037] Since residual austenite improves ductility according to the TRIP effect, the residual austenite is uneventfully contained. However, martensite transformed from austenite is hard, which serves as the starting point of voids. Therefore, the volume fraction of the residual austenite contained in the metal structure is preferably 10% or less.

[0038] Segregation Degree α of Mn: 1.6 or less

$$\alpha = [\text{maximum Mn concentration (mass \%) at a central part of a sheet thickness}]/[\text{average Mn concentration (mass \%) at 1/4 depth position of sheet thickness from a surface}] \ldots \text{(i)}$$

[0039] At the central part of the section of the sheet thickness of the hot-formed steel sheet member, center segregation occurs, which incrassates Mn. Therefore, MnS concentrates on the center as inclusions, which is apt to cause the formation of hard martensite. This causes a difference in hardness between the hard martensite and its circumference, as a result of which the local deformability is deteriorated. Particularly, in a case in which the value of the segregation degree α of Mn represented by the formula (i) exceeds 1.6, the local deformability is remarkably deteriorated. Therefore, in order to improve the local deformability, the α value of the hot-formed steel sheet member is preferably set to 1.6 or less. In order to further improve the local deformability, the α value is more preferably set to 1.2 or less.

[0040] The segregation of Mn in the steel sheet is mainly controlled by a steel sheet composition (particularly an impurity content) and a continuous casting condition, and is not substantially changed after and before hot-rolling and hot-forming. Therefore, the inclusions and segregation situation of the steel sheet for hot-forming are almost the same as those of the hot-formed steel sheet member manufactured by hot-forming the steel sheet for hot-forming. Since the α value is not largely changed by hot-forming, the α value of the hot-formed steel sheet member can also be set to 1.6 or less by setting the α value of the steel sheet for hot-forming to 1.6 or less. The α value of the hot-formed steel sheet member can also be set to 1.2 or less by setting the α value to 1.2 or less.

[0041] The maximum Mn concentration at a central part of the sheet thickness is obtained by the following method. The central part of the sheet thickness of the steel sheet is subjected to line analysis using an electron probe microanalyzer (EPMA). Three measured values are selected in higher order from the analysis results, and the average value thereof is calculated. The average Mn concentration at the 1/4 depth position of the sheet thickness from the surface is obtained by the following method. Similarly, ten places are analyzed at the 1/4 depth position of the steel sheet using EPMA, and the average value thereof is calculated.

Cleanliness Level: 0.08% or less

[0042] In a case in which A-based, B-based, and C-based inclusions described in JIS G 0555 (2003) exist in large amounts in the steel sheet member, the inclusions are apt to serve as the starting point of breaking. In a case in which the inclusions are increased, crack propagation easily occurs, which causes deterioration in the local deformability. Particularly, in the case of the hot-formed steel sheet member having tensile strength of 1.0 GPa or more, the existence fraction of the inclusions is preferably suppressed low. In a case in which the value of the cleanliness level of the steel specified by JIS G 0555 (2003) exceeds 0.08%, the amount of the inclusions is large, which makes it difficult to secure practically sufficient local deformability. Therefore, the value of the cleanliness level of the steel sheet for hot-forming is preferably set to 0.08% or less. The value of the cleanliness level is more preferably set to 0.04% or less in order to further improve the local deformability. The value of the cleanliness level of the steel is obtained by calculating the area percentages of the A-based, B-based, and C -based inclusions.

[0043] Since the value of the cleanliness level is not largely changed by hot-forming, the value of the cleanliness level of the hot-formed steel sheet member can also be set to 0.08% or less by setting the value of the cleanliness level of the steel sheet for hot-forming to 0.08% or less. The value of the cleanliness level of the hot-formed steel sheet member can also be set to 0.04% or less by setting the value of the cleanliness level of the steel sheet for hot-forming to 0.04% or less.

[0044] In the embodiments, the value of the cleanliness level of the steel sheet for hot-forming or the hot-formed steel sheet member is obtained by the following method. Test materials are cut from five places of the steel sheet for hot-forming or the hot-formed steel sheet member. In a case in which the sheet thickness of the steel sheet for hot-forming or the hot-formed steel sheet member is defined as t, the cleanliness level is investigated at each of positions of 1/8t, 1/4t, 1/2t, 3/4t, and 7/8t in the direction of the sheet thickness of each of the test materials by a JIS-G-0555 method. The largest value (lowest cleanliness property) of the cleanliness level in each of the sheet thicknesses is used as the value of the cleanliness level of the test material.

Average Grain Size of Prior γ Grains: 10 μm or less

[0045] In a case in which a prior γ grain size in the hot-formed steel sheet member is decreased, the local deformability is improved. In a steel sheet mainly containing martensite, voids occur at prior γ grain boundaries and boundaries of the lower structures in grains. However, grain refining of prior γ grains can suppress the occurrence of the voids, and improve the local deformability for delaying connection. In a case in which the average grain size of the prior γ exceeds 10 μm, this effect cannot be exhibited. Therefore, the average grain size of the prior γ grains in the hot-formed steel sheet member is set to 10 μm or less. In order to perform grain refining of the prior γ grains, it is effective to decrease a heating temperature, and to delay the dissolution of carbides during heating to suppress the grain growth.

[0046] The average grain size of the prior γ grains can be measured using a method specified by ISO643. That is, the number of crystal grains in a measured view is measured. The average area of the crystal grains is obtained by dividing the area of the measured view by the number of the crystal grains, and the crystal grain size in an equivalent circular diameter is calculated. At that time, it is preferable that the grain on the boundary of the view is measured as 1/2, and a magnification ratio is adjusted so that the number of the crystal grains is set to 200 or more. A plurality of views are preferably measured in order to improve accuracy.

Residual Carbides: 4×10^3 per mm^2 or less

[0047] In the case of hot-forming, sufficient hardenability can be secured by the resolution of carbides generally existing in steel. However, a part of the carbides may remain without being resolved. The residual carbides have an effect of suppressing the growth of γ grains in holding heating during hot-forming by pinning. Therefore, the residual carbides desirably exist during holding heating. As the residual carbides are decreased after hot-forming, the hardenability is improved, which can provide the securement of high strength. Therefore, it is preferable that the number density of the residual carbides can be reduced in a case in which the holding heating is completed.

[0048] In a case in which a number of residual carbides exist, the hardenability after hot-forming may be deteriorated, and the residual carbides serve as the occurrence source of voids to cause deterioration in local deformability. Particularly, in a case in which the number density of the residual carbides exceeds 4×10^3 per mm^2, the hardenability after hot-forming may be deteriorated. Therefore, the number density of the residual carbides existing in the hot-formed steel sheet member is preferably 4×10^3 per mm^2 or less.

(C) Plating Layer

[0049] The high-strength hot-formed steel sheet member according to the embodiments may have a surface on which a plating layer is formed for the purpose of an improvement in corrosion resistance, or the like. The plating layer may be an electroplating layer, and may be a hot-dip plating layer. Examples of the electroplating layer include electrogalvanizing, electric Zn-Ni alloy plating, and electric Zn-Fe alloy plating. Examples of the hot-dip plating layer include hot dip galvanizing, alloyed hot dip galvanizing, molten aluminum plating, molten Zn-Al alloy plating, molten Zn-Al-Mg alloy plating, and molten Zn-Al-Mg-Si alloy plating. A plating deposition amount is not particularly limited, and may be adjusted within a general range.

(D) Method for Manufacturing Steel Sheet for Hot-Forming

[0050] The manufacturing conditions of the steel sheet for hot-forming used for manufacturing the steel sheet member for hot-forming according to the embodiments are not particularly limited, but the steel sheet for hot-forming can be suitably manufactured by using a manufacturing method to be shown below.

[0051] The steel having the above-mentioned chemical composition is melted in a furnace, and a slab is then produced by casting. In order to set the cleanliness level of the steel sheet to 0.08% or less, it is desirable to set the heating temperature of molten steel to a temperature higher by 5°C or more than the liquidus-line temperature of the steel in a case in which the molten steel is continuously cast, and to suppress the amount of the molten steel to be cast per unit time to 6 t/min or less.

[0052] In a case in which the amount to be cast per unit time of the molten steel exceeds 6 t/min during continuous casting, the molten steel is fast stirred in a mold. Thereby, inclusions are apt to be trapped by a solidifying shell, which causes an increase in the inclusions in the slab. In a case in which the molten steel heating temperature is less than a temperature higher by 5°C than the liquidus-line temperature, the viscosity of the molten steel is increased, and thereby, the inclusions are less likely to float in a continuous-casting machine. As a result, the inclusions in the slab are increased, which is apt to cause deterioration in cleanliness property.

[0053] The molten steel is cast with the molten steel heating temperature set to 5°C or higher from the liquidus-line temperature of the molten steel and the amount of the molten steel to be cast per unit time set to 6 t/min or less, which is less likely to cause the introduction of the inclusions into the slab. As a result, the amount of the inclusions at the stage in which the slab is produced can be effectively decreased, which can easily achieve the steel sheet cleanliness level of 0.08% or less.

[0054] In a case in which the molten steel is continuously cast, the molten steel heating temperature is more desirably set to a temperature higher by 8°C or more than the liquidus-line temperature, and the amount of the molten steel to be cast per unit time is more desirably set to 5 t/min or less. By setting the molten steel heating temperature to a temperature higher by 8°C or more than the liquidus-line temperature, and setting the amount of the molten steel to be cast per unit time to 5 t/min or less, the cleanliness level is easily set to 0.04% or less, which is desirable.

[0055] In order to suppress the concentration of MnS causing deterioration in local deformability, a center segregation reducing treatment is desirably performed to reduce the center segregation of Mn. Examples of the center segregation reducing treatment include a method of discharging molten steel in which Mn is incrassated in an unsolidified layer before a slab is completely solidified.

[0056] Specifically, molten steel in which Mn before being completely solidified is incrassated can be discharged by a treatment such as electromagnetic stirring or unsolidified layer reduction. The electromagnetic stirring treatment can be performed by stirring unsolidified molten steel at from 250 to 1000 gausses, for example. The unsolidified layer reduction treatment can be performed by reducing a last solidified part at the slope of about 1 mm/m, for example.

[0057] The slab obtained by the above-mentioned method may be subjected to a soaking treatment if necessary. By performing the soaking treatment, segregated Mn is diffused, which can provide a reduction in a segregation degree. A preferable soaking temperature in a case in which the soaking treatment is performed is from 1200 to 1300°C, and a preferable soaking time is from 20 to 50 hours.

[0058] Then, the slab is hot-rolled. As hot-rolling conditions, from the viewpoint of more uniformly producing carbides, it is preferable that a hot-rolling initiation temperature is set to a temperature region of from 1000 to 1300°C, and a hot-rolling completion temperature is set to 850°C or higher. A winding temperature is preferably higher from the viewpoint of processability. However, in a case in which the winding temperature is too high, scale formation causes a decrease in yield, and thereby the winding temperature is preferably from 500 to 650°C. A hot-rolled steel sheet obtained by hot-rolling is subjected to a descale treatment by pickling or the like.

[0059] In the embodiments, in order to perform grain refining of priory grains after hot-forming and to reduce the number density of residual carbides, the hot-rolled steel sheet subjected to the descale treatment is preferably annealed to produce a hot-rolled annealed steel sheet.

[0060] In order to provide the fine prior γ grain size after hot-forming, the growth of the γ grains is preferably suppressed by the carbides in solution. However, in order to improve the hardenability, to secure the high strength, and to suppress the occurrence of voids in the hot-formed steel sheet member, the number density of the residual carbides is preferably reduced.

[0061] In order to provide the fine prior γ grain size in the hot-formed steel sheet member and to reduce the number density of the residual carbides, the form of the carbides existing in the steel sheet before hot-forming and the incrassating degree of elements in the carbides are important. It is desirable that the carbides are finely dispersed. However, since the carbides are fast dissolved in the case, a grain growth suppressing effect cannot be expected. In a case in which elements such as Mn and Cr are incrassated in the carbides, the carbides are less likely to be solved. Therefore, it is desirable that the carbides in the steel sheet before hot-forming are finely dispersed, and the incrassating degree of the elements in the carbides is higher.

[0062] The form of the carbides can be controlled by adjusting the annealing condition after hot-rolling. Specifically, it is preferable that the annealing temperature is set to an Ac1 point or less and the Ac1 point-100°C or higher, and an annealing time is 5 hours or less.

[0063] In a case in which a winding temperature after hot-rolling is set to 550°C or lower, the carbides are likely to be finely dispersed. However, since the incrassating degree of the elements in the carbides is also decreased, the incrassating of the elements is advanced by annealing.

[0064] In a case in which the winding temperature is 550°C or higher, perlite is generated, and the incrassating of the elements to the carbides in the perlite is advanced. In this case, in order to divide the perlite to disperse the carbides, annealing is performed.

[0065] As the steel sheet for hot-formed steel sheet member in the embodiments, the above-mentioned hot-rolled annealed steel sheet, a cold-rolled steel sheet obtained by cold-rolling the hot-rolled annealed steel sheet, or a cold-rolled annealed steel sheet obtained by annealing the cold-rolled steel sheet can be used. A treating step may be selected if appropriate according to the request level of the accuracy of the sheet thickness of a product, or the like. Since the carbides are hard, the form of the carbides is not changed even in a case in which cold-rolling is performed, and the existence form before cold-rolling is maintained even after cold-rolling.

[0066] The cold-rolling may be performed using a usual method. From the viewpoint of securing favorable flatness, a reduction ratio in the cold-rolling is preferably set to 30% or more. In order to avoid an excessive load, the reduction ratio in the cold-rolling is preferably set to 80% or less.

[0067] In a case in which the cold-rolled steel sheet is annealed, it is desirable that the cold-rolled steel sheet is preliminarily subjected to a treatment such as degreasing. The annealing is preferably performed at an Ac1 point or less, for hours or less, preferably for 3 hours or less for the purpose of cold-rolling strain lessening.

(E) Method for Forming Plating Layer

[0068] As described above, the hot-formed steel sheet member according to the embodiments may have a surface on which a plating layer is formed for the purpose of an improvement in corrosion resistance, or the like. The plating layer is desirably formed on the steel sheet before being subjected to hot-forming. In a case in which zinc-based plating is applied to the surface of the steel sheet, molten zinc-based plating is preferably applied in a continuous hot dip galvanizing line from the viewpoint of productivity. In the case, annealing may be performed before a plating treatment in the continuous hot dip galvanizing line. Only a plating treatment may be performed without being annealed with a heat holding temperature set to a low temperature. An alloyed molten zinc sheetd sheet steel may be provided by performing an alloying heat treatment after hot dip galvanizing. The zinc-based plating can also be applied by electroplating. The zinc-based plating can be applied to at least a part of the surface of the steel material. However, generally, the zinc-based plating is entirely applied to one surface or both surfaces of the steel sheet.

(F) Method for Manufacturing Hot-Formed Steel Sheet Member

[0069] By hot-forming the steel sheet for hot-forming, a high-strength hot-formed steel sheet member can be obtained. From the viewpoint of suppressing the grain growth, the heating rate of the steel sheet during hot-forming is desirably 20°C/sec or higher, and more preferably 50°C/sec or higher. The heating temperature of the steel sheet during hot-forming is desirably set to a temperature of more than an Ac_3 point and 1050°C or lower. In a case in which the heating temperature is the Ac_3 point or less, ferrite, perlite, or bainite remains in the steel sheet without providing an austenite single phase state before hot-forming. As a result, desired hardness may not be obtained without providing the metal structure mainly containing martensite after hot-forming. This causes not only an increase in a variation in hardness of the hot-formed steel sheet member but also deterioration in local deformability.

[0070] In a case in which the heating temperature exceeds 1050°C, the austenite is coarse, which may cause deterioration in the local deformability of the steel sheet member. Therefore, the heating temperature of the steel sheet during hot-forming is preferably set to 1050°C or lower. In a case in which a heating time is less than 1 min, the single-phasing of the austenite may be insufficient even if heating is performed. Furthermore, since the dissolution of the carbides is insufficient, the number density of the residual carbides is increased even if the γ grain size is refined. In a case in which the heating time exceeds 10 min, the austenite is coarse, which may cause deterioration in the local deformability of the hot-formed steel sheet member. Therefore, the heating time of the steel sheet during hot-forming is desirably set to from 1 to 10 min.

[0071] In a case in which a hot-forming initiation temperature is less than the Ar_3 point, ferrite transformation starts. Therefore, even if forcible cooling is then performed, the structure mainly containing martensite may not be provided. Therefore, the hot-forming initiation temperature is desirably the Ar_3 point or more. Rapid cooling is desirably performed at the cooling rate of 10°C/sec or higher after hot-forming, and rapid cooling is more desirably performed at the rate of 20°C/sec or higher. The upper limit of the cooling rate is not particularly specified.

[0072] In order to obtain a hot-formed steel sheet member having a metal structure mainly containing martensite having a less variation in hardness, the steel sheet after hot-forming is desirably rapidly cooled until the surface temperature of the steel sheet becomes 350°C or lower. A cooling end temperature is preferably set to 100°C or lower, and more preferably room temperature.

[0073] Hereinafter, the embodiments will be more specifically described with reference to Examples, but the present invention is not limited to these Examples.

Examples

[0074] Steel having chemical components shown in Table 1 was melted in a test converter, and subjected to continuous casting in a continuous casting testing machine, to produce slabs each having a width of 1000 mm and a thickness of 250 mm. Symbol * used in Table 1 means departing from the composition range of the embodiments. Under conditions shown in Table 2, the heating temperature of molten steel and the amount of molten steel to be cast per unit time were adjusted. The cooling rate of each of the slabs was controlled while the water amount of a secondary cooling spray band was changed. A center segregation reducing treatment is performed by carrying out soft reduction at the slope of 1 mm/m using rolls in a solidified terminal part and discharging the incrassated molten steel of a last solidified part. A part of the slabs were then subjected to a soaking treatment under conditions of 1250°C and 24 hours.

[Table 1]

steel type	chemical composition (mass %, balance: Fe and impurities)																molten steel line temperature (°C)
	C	Si	Mn	P	S	sol.Al	N	Cr	Ti	B	Nb	Cu	Ni	Mo	V	Ca	
A	0.14	0.15	1.25	0.004	0.002	0.04	0.0015	0.48	0.018	0.0015	-	-	-	-	-	-	1520
B	0.14	0.10	1.00	0.005	0.002	0.03	0.0020	0.70	0.020	0.0016	-	-	-	-	-	-	1518
C	0.09	0.05	1.10	0.003	0.002	0.05	0.0024	1.00	0.023	0.0018	0.08	-	-	-	-	-	1523
D	0.15	0.15	1.20	0.004	0.002	0.05	0.0020	0.48	0.022	0.0030	-	0.1	-	-	-	-	1518
E	0.13	0.05	1.30	0.005	0.002	0.02	0.0030	0.60	0.025	0.0022	-	-	0.3	-	-	-	1519
F	0.11	0.10	1.05	0.004	0.002	0.03	0.0012	0.70	0.020	0.0020	-	-	-	0.1	-	-	1522
G	0.12	0.02	1.40	0.005	0.002	0.04	0.0020	1.30	0.018	0.0019	-	-	-	-	0.01	-	1517
H	0.13	0.05	1.30	0.004	0.003	0.03	0.0022	0.80	0.022	0.0022	-	-	-	-	-	0.003	1519
I	0.15	0.05	1.30	0.003	0.012*	0.04	0.0023	1.00	0.020	0.0015	-	-	-	-	-	-	1517
J	0.11	0.10	2.40*	0.005	0.002	0.05	0.0025	0.30	0.015	0.0020	-	-	-	-	-	-	1515
K	0.14	1.00*	1.30	0.004	0.002	0.03	0.0020	0.30	0.019	0.0018	-	-	-	-	-	-	1508
L	0.20*	0.15	1.30	0.006	0.002	0.04	0.0015	0.40	0.022	0.0015	-	-	-	-	-	-	1513
M	0.11	0.15	0.80	0.005	0.002	0.04	0.0025	0.20*	0.021	0.0015	-	-	-	-	-	-	1523

[Table 2]

test number	steel type	steel sheet	molten steel heating temperature (°C)	amount of molten steel to be cast (t/min)	slab center segregation reducing treatment	soaking treatment	winding temperature (°C)	annealing after hot-rolling		cold-rolling	annealing after cold-rolling	hot-forming		tensile strength (MPa)	variation in hardness			metal structure			prior γ grain size	cleanliness level (%)	degree of segregation α	number density of residual carbides (per mm^2)	notch elongation (%)	
								temperature (°C)	time (h)			temperature (°C)	holding time (h)		HS$_{80}$	HS$_{10}$	ΔHv	volume fraction of low-temperature transformation structure (%)	volume fraction of ferrite (%)	volume fraction of residual γ (%)						
1	A	hot-rolling	1550	4.3	YES	1250°C×24h	510	620	1	NO	NO	880	90	1236	391	371	20	95.6	1.2	3.2	8.8	0.02	1.2	1.0×10^{3}	7.9	Examples
2	A	cold-rolling	1550	8	YES	1250°C×24h	510	620	1	YES	YES	880	90	1226	386	363	23	95.4	1.5	3.1	8.3	0.09	1.2	1.5×10^{3}	5.5	Comparative Examples
3	A	cold-rolling	1550	4.3	NO	NO	510	620	1	YES	NO	880	90	1230	388	364	24	95.8	1.3	2.9	9.0	0.02	1.7	1.8×10^{3}	5.4	Comparative Examples
4	B	hot-rolling	1550	3.5	YES	1250°C×24h	510	620	1	NO	NO	880	90	1345	419	399	20	94.8	2.0	3.2	8.6	0.02	1.2	1.6×10^{3}	6.8	Examples
5	B	cold-rolling	1520	5.5	YES	NO	510	620	1	YES	NO	880	90	1351	422	403	19	94.5	2.1	3.4	9.5	0.09	1.3	2.0×10^{3}	5.4	Comparative Examples
6	B	cold-rolling	1550	3.5	YES	1250°C×24h	510	620	1	YES	NO	820	90	1230	420	404	16	87.0	9.6	3.0	5.5	0.03	1.3	8.0×10^{3} *	4.5	Comparative Examples
7	C	cold-rolling	1550	5.1	YES	1250°C×24h	510	620	1	YES	YES	880	90	1169	376	359	16	95.9	1.0	3.1	5.4	0.02	1.2	2.2×10^{3}	8.6	Examples
8	D	cold-rolling	1550	5.5	YES	1250°C×24h	510	620	1	YES	YES	880	90	1384	429	409	20	94.6	2.0	3.4	8.7	0.02	1.2	1.1×10^{3}	6.5	Examples
9	D	cold-rolling	1550	5.5	YES	1250°C×24h	510	620	1	YES	YES	1100	90	1356	426	408	18	96.0	0.0	4.0	20.1*	0.02	1.2	0.1×10^{3}	5.4	Comparative Examples
10	E	cold-rolling	1550	3.6	YES	1250°C×24h	510	620	1	YES	NO	880	90	1305	407	387	20	94.6	1.2	4.2	9.2	0.02	1.1	1.4×10^{3}	7.2	Examples
11	E	cold-rolling	1550	3.6	YES	1250°C×24h	680	-	-	YES	NO	880	90	1255	389	350	39	94.2	3.5	2.3	6.5	0.02	1.1	4.5×10^{3} *	5.7	Comparative Examples
12	F	cold-rolling	1550	2.1	YES	1250°C×24h	510	620	1	YES	NO	880	90	1222	384	362	22	94.8	1.3	3.9	8.6	0.02	1.2	1.5×10^{3}	7.2	Examples
13	G	cold-rolling	1550	5.2	YES	1250°C×24h	510	620	1	YES	YES	880	90	1276	402	384	18	94.3	0.5	5.2	8.4	0.02	1.1	2.9×10^{3}	7.8	Examples
14	G	cold-rolling	1550	5.2	YES	1250°C×24h	510	650	20	YES	YES	880	90	1055	360	265	95	81.0	18.1	0.9	5.1	0.02	1.1	8.5×10^{3} *	4.8	Comparative Examples
15	H	cold-rolling	1550	3.9	YES	1250°C×24h	510	620	1	YES	YES	880	90	1315	412	394	18	94.7	1.3	4.0	9.3	0.03	1.1	1.8×10^{3}	7.3	Examples
16	I*	hot-rolling	1550	3.9	YES	1250°C×24h	510	620	1	NO	NO	880	90	1384	429	409	20	94.8	0.6	4.6	8.8	0.09	1.1	2.3×10^{3}	5.1	Comparative Examples
17	J*	cold-rolling	1550	2.8	NO	NO	510	620	1	YES	NO	880	90	1236	391	372	19	94.8	0.4	4.8	8.4	0.04	1.9	0.8×10^{3}	5.6	
18	K*	cold-rolling	1550	2.7	YES	1250°C×24h	510	620	1	YES	YES	880	90	1343	418	340	77	86.5	11.0	2.5	6.5	0.02	1.2	2.9×10^{3}	6.6	
19	L*	cold-rolling	1550	5.1	YES	1250°C×24h	510	620	1	YES	NO	880	90	1550	467	441	26	94.2	2.0	3.8	10.2*	0.02	1.1	1.1×10^{3}	4.6	
20	M*	cold-rolling	1550	4.5	YES	1250°C×24h	510	620	1	YES	NO	880	90	1242	394	222	172	97.7	0.5	1.8	8.9	0.02	1.2	0.7×10^{3}	7.8	

[0075] The obtained slabs were hot-rolled with a hot-rolling testing machine, to produce 3.0-mm-thick hot-rolled steel sheets. Each of the hot-rolled steel sheets was wound, then subjected to pickling, and further annealed. Apart of the steel sheets were further cold-rolled with a cold-rolling testing machine, to produce 1.5-mm-thick cold-rolled steel sheets. Furthermore, a part of the cold-rolled steel sheets were annealed at 600°C for 2 h to obtain cold-rolled annealed steel sheets.

[0076] Then, as shown in Fig. 1 and Fig. 2, the steel sheets 1 for hot-forming were subjected to hot pressing (hat forming) with a mold (punch 11, dice 12) using a hot pressing test apparatus, to obtain hot-formed steel sheet members 2. The steel sheets were heated at various surface temperatures rainging from 820°C to 1100°C in a heating furnace, held at the temperatures for 90 seconds, then taken out from the heating furnace, immediately subjected to hot pressing with the mold with a cooling device, and subjected to a quenching treatment simultaneously with forming. The hot-formed steel sheet members were evaluated as follows. The evaluation results are shown in Table 2. In Table 2, "hot-rolling" means a 3.0-mm-thick-hot-rolled steel sheets subjected to hot-rolling, and "cold-rolling" means a 1.5-mm-thick-cold-rolled steel sheet obtained by further cold-rolling the hot-rolled steel sheets. Symbol * means departing from the range of the embodiments.

<Evaluation of Mechanical Characteristics of Hot-Formed Steel Sheet Member>

[0077] A JIS No. 5 tensile test pieces were obtained from the rolling right-angle direction of the hot-formed steel sheet members, and subjected to a tensile test according to JIS Z2241 (2011) to measure tensile strength (TS).

<Identification of Metal Structure>

[0078] The hot-formed steel sheet members were cut to samples so that the central part of the sheet thickness of sections parallel to the rolling direction, of the hot-formed steel sheet members were viewing surfaces, and the samples were then subjected to mirror polishing. Then, the samples were subjected to Nital corrosion, and the metal structures of five views of each of the samples were observed using a scanning electron microscope (magnification ratio: 2000). By subjecting the obtained microphotograph to an image treatment, the area fraction of ferrite was obtained. It was used as the volume fraction of ferrite. The volume fraction of residual austenite in the metal structure was obtained using X diffraction (XRD). The balance thereof was calculated as the volume fraction of a low-temperature transformation structure. The residual γ volume fraction was obtained from the intensity ratio of diffraction intensity $I\alpha(200)$ of (200) of ferrite, diffraction intensity $I\alpha(211)$ of (211) of ferrite, diffraction intensity $I\gamma$ (220) of (220) of austenite, and diffraction intensity $I\gamma$ (311) of (311) of austenite according to X diffraction using a Mo bulb after chemically polishing the 1/8 inner layer of the sheet thickness from the surface of each of the steel sheets.

$$V\gamma(\text{volume }\%) = 0.25 \times \{I\gamma(220)/(1.35 \times I\alpha(200) + I\gamma(220)) + I\gamma(220)/(0.69 \times I\alpha(211) + I\gamma(220)) + I\gamma(311)/(1.5 \times I\alpha(200) + I\gamma(311)) + I\gamma(311)/(0.69 \times I\alpha(211) + I\gamma(311))\}$$

<Evaluation of Cleanliness Level>

[0079] Test materials were cut from five places of the hot-formed steel sheet members. The cleanliness level was investigated at each of positions of 1/8t, 1/4t, 1/2t, 3/4t, and 7/8t with respect to the sheet thickness t of each of the test materials by a point counting method. The largest value (lowest cleanliness property) of the cleanliness level in each of the sheet thicknesses was used as the value of the cleanliness level of the test material.

<Measurement of Segregation Degree α of Mn>

[0080] The central part of the sheet thickness of the hot-formed steel sheet member was subjected to line analysis using EPMA. Three measured values were measured at high order from the analysis results, and the average value thereof was then calculated to obtain the maximum Mn concentration in the central part of the sheet thickness. Ten places were analyzed using EPMA at the 1/4 depth position of the sheet thickness from the surface of the hot-formed steel sheet member, to obtain the average value thereof. The average Mn concentration at the 1/4 depth position of the sheet thickness from the surface was obtained. The segregation degree α of Mn was obtained by dividing the maximum Mn concentration in the central part of the sheet thickness by the average Mn concentration at the 1/4 depth position of the sheet thickness from the surface.

<Measurement of Average Grain Size of Prior γ Grains>

[0081] The average grain size of the prior γ grains in the hot-formed steel sheet member was obtained by measuring the number of crystal grains in a measured view, dividing the area of the measured view by the number of the crystal grains to obtain the average area of the crystal grains, and calculating a crystal grain size in an equivalent circular diameter. At that time, the grain on the boundary of the view was measured as 1/2, and an observation magnification ratio was adjusted if appropriate so that the number of the crystal grains was set to 200 or more.

<Number Density of Residual Carbides>

[0082] The surface of the hot-formed steel sheet member was corroded using a picral liquid, and magnified in a size of 2000 times with a scanning electron microscope. A plurality of views were observed. At this time, the number of views in which carbides existed was counted to calculate the number per 1 mm^2.

<Measurement of Local Deformability>

[0083] The local deformability was measured according to a notch tensile test. A tensile test piece had a parallel part width of 16.5 mm and a parallel part length of 60 mm, and obtained with a rolling direction as a longitudinal direction. A 2-mm-deep V notch was processed in the length central part of the tensile test piece, and the processed tensile test piece was used as a notch tensile test piece. The thickness of the notch test piece was set to 1.4 mm. The shape of the notch tensile test piece is shown in Fig. 3. The tensile test was performed using the notch tensile test piece, and notch elongation in a case in which the notch tensile test piece was broken at a V notched part was measured, to evaluate the local deformability. A reference point distance was set to 5 mm, and a tensile speed (crosshead speed) during the tensile test was set to 0.5 mm/min.

<Variation in Hardness>

[0084] The following test was performed in order to evaluate hardness stability. Steel sheets for hot-forming were heated at 10°C/sec to 900°C by a heat treatment simulator, and then held for 150 sec. Then, the steel sheets for hot-forming were cooled at the cooling rates of about 80°C/sec and 10°C/sec to room temperature. Each of the samples was subjected to a Vickers hardness test at the 1/4 position of the sheet thickness of the section. Hardness measurement was performed based on JIS Z 2244 (2009) at five points with a test force set to 9.8 N, and the average thereof was obtained. The average value of the hardnesses at the cooling rate of about 80°C/sec and the average value of the hardnesses at the cooling rate of 10°C/sec were defined as HS_{80} and HS_{10}, and the difference ΔHv thereof was used as the index of the hardness stability.

[0085] In order to evaluate the hardness stability and local deformability of each of the samples, the samples having ΔHv of 50 or less and notch elongation of 6% or more were determined to be favorable.

[0086] As shown in Table 2, the test number 2 had a steel composition satisfying the range of the embodiments, but the amount of molten steel to be cast per unit time was large. Thereby, the value of the cleanliness level exceeded 0.08%, which resulted in poor local deformability.

[0087] Since the test number 3 was not subjected to a center segregation reducing treatment and a soaking treatment, the segregation degree of Mn exceeded 1.6, which resulted in poor local deformability.

[0088] Since the test number 5 had a low molten steel heating temperature, the value of the cleanliness level exceeded 0.08%, which resulted in poor local deformability.

[0089] Since the test number 6 had a low hot-forming temperature, the volume fraction of ferrite exceeded 3% after hot-forming, which resulted in poor hardness stability. Furthermore, the number density of residual carbides was also as high as 8.0×10^3 per mm^2, which resulted in poor local deformability.

[0090] Since the test number 9 had a high heating temperature during hot-forming, the prior γ grain size was increased, which resulted in poor local deformability.

[0091] Since the test number 11 had a high winding temperature after hot-rolling, the density of residual carbides was increased, which resulted in poor local deformability.

[0092] Since the test number 14 had a high annealing temperature after hot-rolling and a long annealing time, the volume fraction of ferrite exceeded 3% after hot-forming, which resulted in poor hardness stability. The insufficient dissolution of carbides caused an increase in the density of residual carbides, which resulted in poor local deformability.

[0093] Since the test number 16 had an S content exceeding the upper limit value of the range of the embodiments, the value of the cleanliness level exceeded 0.08%, which resulted in poor local deformability.

[0094] Since the test number 17 had a Mn content exceeding the upper limit value of the range of the embodiments, the segregation degree of Mn exceeded 1.6, which resulted in poor local deformability.

[0095] Since the test number 18 had an Si content exceeding the upper limit value of the range of the embodiments, an A_3 point was increased, and the volume fraction of ferrite exceeded 3% after hot-forming, which resulted in poor hardness stability.

[0096] The test number 19 had a C content exceeding the upper limit value of the range of the embodiments, which resulted in poor local deformability.

[0097] The test number 20 had a Cr content lower than the range of the embodiment, which resulted in poor hardness stability.

[0098] The test numbers 1, 4, 7, 8, 10, 12, 13, and 15 satisfying the range of the embodiments were excellent in both hardness stability and local deformability.

[0099] The entire disclosures of Japan Patent Application No. 2014-101443 filed in May 15, 2014 and Japan Patent Application No. 2014-101444 filed in May 15, 2014 are incorporated herein by reference.

[0100] All publications, patent applications, and technical standards described herein are herein incorporated by reference to the same extent as if each individual publication, patent application, or technical standard was specifically and individually indicated to be incorporated by reference.

[0101] As described above, the various typical embodiments have been described, but the invention is not limited to these embodiments. The range of the invention is limited by only the following claims.

Claims

1. A hot-formed steel sheet member having a chemical composition consisting of, in terms of mass %, from 0.08 to 0.16% of C, 0.19% or less of Si, from 0.40 to 1.50% of Mn, 0.02% or less of P, 0.01% or less of S, from 0.01 to 1.0% of sol. Al, 0.01% or less of N, from 0.25 to 3.00% of Cr, from 0.01 to 0.05% of Ti, from 0.001 to 0.01% of B, from 0 to 0.50% of Nb, from 0 to 2.0% of Ni, from 0 to 1.0% of Cu, from 0 to 1.0% of Mo, from 0 to 1.0% of V, from 0 to 0.005% of Ca, and a remainder consisting of Fe and impurities,
   wherein a total volume fraction of martensite, tempered martensite, and bainite is 50% or more, and a volume fraction of ferrite is 3% or less,
   an average grain size of prior γ grains is 10 μm or less, and
   a number density of residual carbides which are present is 4×10^3 per mm^2 or less.

2. The hot-formed steel sheet member according to claim 1, wherein the chemical composition comprises one or more selected from the group consisting of, in terms of mass %, from 0.003 to 0.50% of Nb, from 0.01 to 2.0% of Ni, from 0.01 to 1.0% of Cu, from 0.01 to 1.0% of Mo, from 0.01 to 1.0% of V, and from 0.001 to 0.005% of Ca.

3. The hot-formed steel sheet member according to claim 1 or 2, wherein a value of a cleanliness level of steel specified by JIS G 0555 (2003) is 0.08% or less.

4. The hot-formed steel sheet member according to any one of claims 1 to 3, wherein a segregation degree α of Mn represented by the following formula (i) is 1.6 or less,

$$\alpha = [\text{maximum Mn concentration (mass \%) at a central part of a sheet thickness}]/[\text{average Mn concentration (mass \%) at a 1/4 depth position of the sheet thickness from a surface}] \ldots \text{(i)}.$$

5. The hot-formed steel sheet member according to any one of claims 1 to 4, wherein the steel sheet member has a surface on which a plating layer is formed.

6. The hot-formed steel sheet member according to any one of claims 1 to 5, wherein the steel sheet member has tensile strength of 1.0 GPa or more.

FIG.1

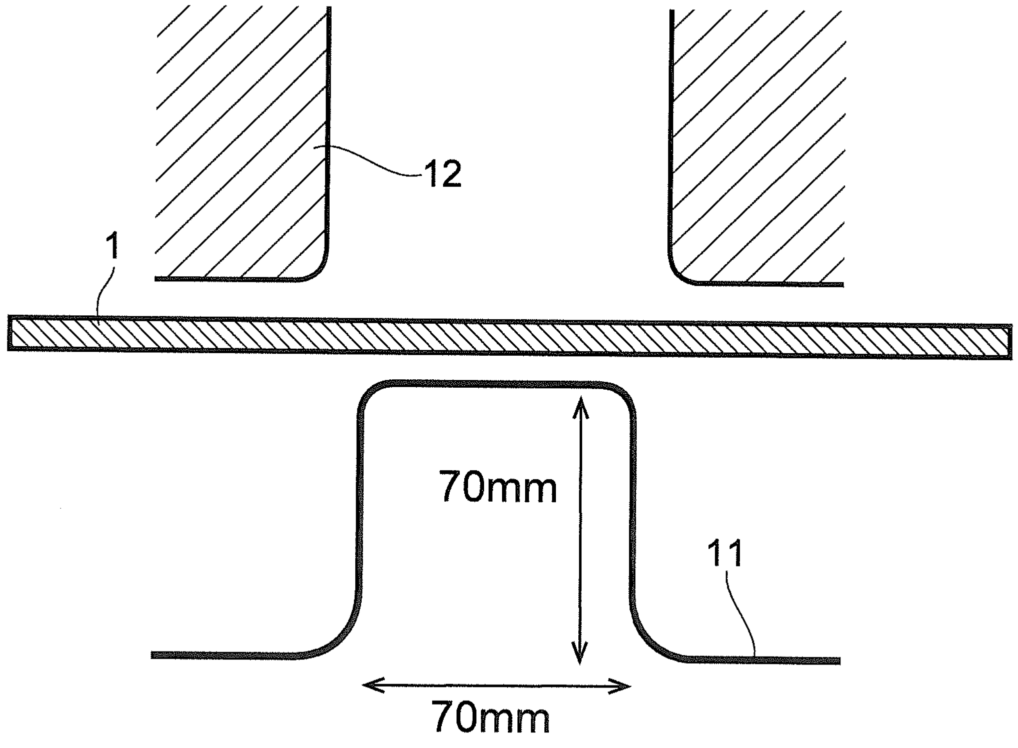


FIG.2

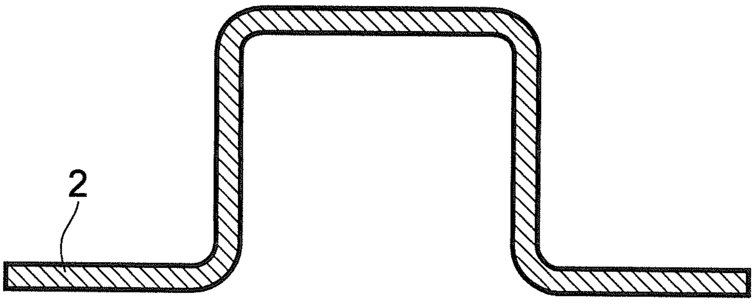
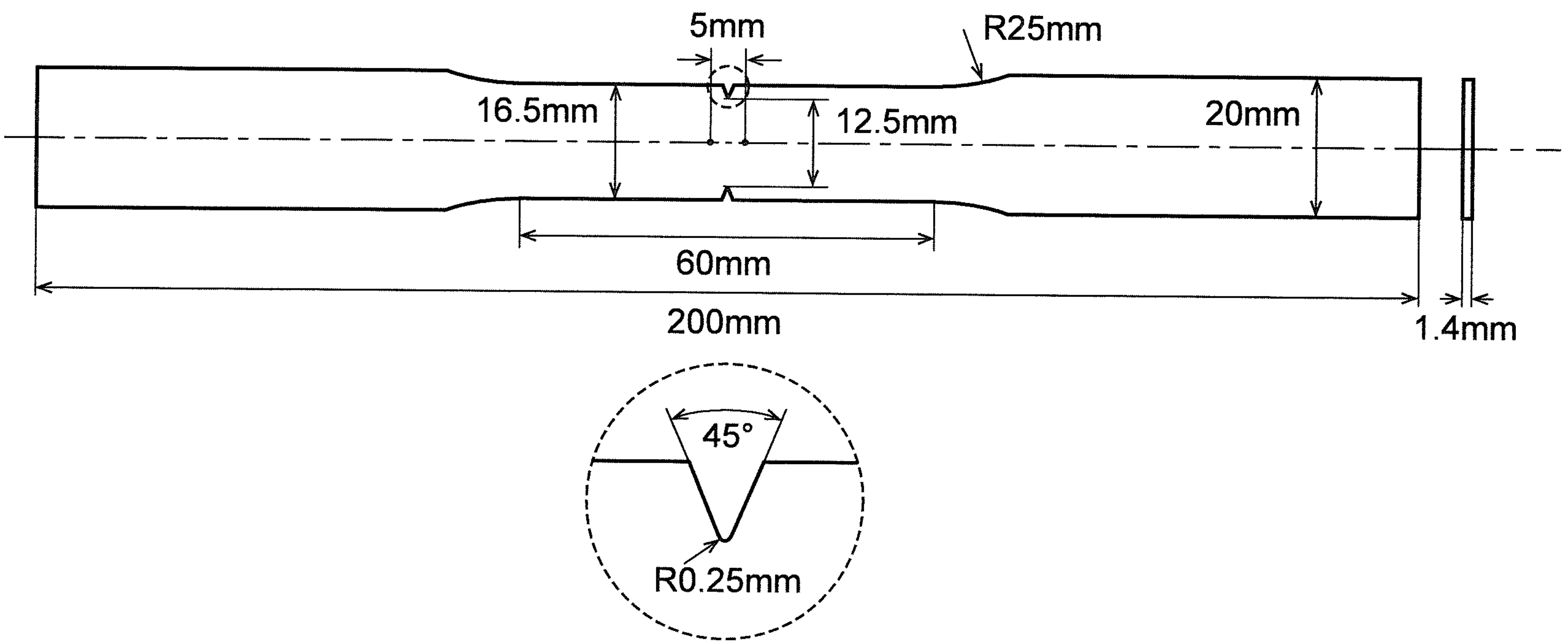


FIG.3



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2015/064101

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C21D9/46*(2006.01)i, *C22C38/54*(2006.01)i, *C21D1/18*(2006.01)n, *C21D9/00*(2006.01)n

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, C21D9/46, C22C38/54, C21D1/18, C21D9/00

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	1996-2015
Kokai Jitsuyo Shinan Koho	1971-2015	Toroku Jitsuyo Shinan Koho	1994-2015

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.
A	WO 2012/157581 A1 (Nippon Steel Corp.), 22 November 2012 (22.11.2012), entire text; all drawings & JP 5556961 B2 & US 2014/0037980 A1 & EP 2708613 A1 & CA 2832901 A1 & TW 201303042 A1 & CN 103534375 A & KR 10-2013-0140169 A & MX 2013013150 A	1-6
A	WO 2013/105631 A1 (Nippon Steel & Sumitomo Metal Corp.), 18 July 2013 (18.07.2013), entire text; all drawings & JP 5382278 B1 & US 2015/0050519 A1 & EP 2803746 A1 & TW 201343932 A & CN 104040008 A & CA 2863218 A1 & KR 10-2014-0102310 A & MX 2014008429 A	1-6

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

*	Special categories of cited documents:
"A"	document defining the general state of the art which is not considered to be of particular relevance
"E"	earlier application or patent but published on or after the international filing date
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"O"	document referring to an oral disclosure, use, exhibition or other means
"P"	document published prior to the international filing date but later than the priority date claimed
"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&"	document member of the same patent family

Date of the actual completion of the international search
03 August 2015 (03.08.15)

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Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2015/064101

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2006-183139 A (JFE Steel Corp.), 13 July 2006 (13.07.2006), entire text; all drawings (Family: none)	1-6
A	JP 2007-314817 A (Sumitomo Metal Industries, Ltd.), 06 December 2007 (06.12.2007), entire text; all drawings (Family: none)	1-6
A	JP 2007-211276 A (Sumitomo Metal Industries, Ltd.), 23 August 2007 (23.08.2007), entire text; all drawings (Family: none)	1-6
A	WO 2009/082091 A1 (POSCO), 02 July 2009 (02.07.2009), entire text; all drawings & KR 10-2009-0070150 A & CN 101910438 A	1-6

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- JP 2006213959 A **[0005] [0007]**
- JP 2007314817 A **[0006] [0007]**
- JP 2014101443 A **[0099]**
- JP 2014101444 A **[0099]**