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(54) **HOT-ROLLED STEEL SHEET**

(57) This hot-rolled steel sheet has a predetermined chemical composition, in which, when a region of 1/8 to 3/8 of a sheet thickness in a sheet thickness direction from a surface is defined as a 1/4 depth position, a microstructure at the 1/4 depth position includes, by area fraction, retained austenite: less than 3.0%, ferrite: less than

30.0%, and pearlite: less than 5.0%, at the 1/4 depth position, an average number density of Ti-based carbides having a longest diameter of 15 nm or more is 1.0×10^4 /mm² or more, and an average grain size d_g is 15.0 μ m or less, and a tensile strength is 980 MPa or more.

EP 4 400 621 A1

Description

[Technical Field of the Invention]

[0001] The present invention relates to a hot-rolled steel sheet. Specifically, the present invention relates to a hot-rolled steel sheet that is formed into various shapes by press working or the like to be used, and particularly relates to a hot-rolled steel sheet that has high strength and excellent shearing workability.

[0002] Priority is claimed on Japanese Patent Application No. 2021-146231, filed September 08, 2021, the content of which is incorporated herein by reference.

[Related Art]

[0003] In recent years, from the viewpoint of protecting the global environment, efforts have been made to reduce the amount of carbon dioxide gas emission in many fields. Vehicle manufacturers are also actively developing techniques for reducing the weight of vehicle bodies for the purpose of reducing fuel consumption. However, it is not easy to reduce the weight of vehicle bodies since the emphasis is also placed on improvement in collision resistance to secure the safety of the occupants.

[0004] In order to achieve both the reduction in the weight of vehicle bodies and collision resistance, thinning a member using a high strength steel sheet has been examined. Therefore, there is a strong demand for a steel sheet having both high strength and excellent formability, and several techniques have been hitherto proposed to meet this demand. Vehicle members are formed by press forming, and the press-formed blank sheet is often manufactured by shearing, which is highly productive. A blank sheet manufactured by shearing needs to be excellent in terms of end surface accuracy after shearing. For example, when a surface roughness of a fractured surface after shearing becomes large, fatigue properties and bendability decrease.

[0005] Regarding the shearing workability, for example, Patent Document 1 discloses a technique for controlling a burr height after punching by controlling a ratio d_s/d_b of a ferrite grain size d_s of a surface layer to a ferrite grain d_b of an inside to 0.95 or less.

[0006] Patent Document 2 discloses a technique for improving peeling or warpage on an end surface of a sheet by reducing a P content.

[Prior Art Document]

[Patent Document]

[0007]

[Patent Document 1] Japanese Unexamined Patent Application, First Publication No. H10-168544

[Patent Document 2] Japanese Unexamined Patent Application, First Publication No. 2005-298924

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0008] However, Patent Document 1 is targeted at IF steel, and there are cases where it is difficult to apply Patent Document 1 to members having a strength as high as 980 MPa or more. In Patent Document 2, a strength of 980 MPa or more cannot be obtained, and a fractured surface roughness at a sheared end surface after shearing is not examined.

[0009] The present invention has been made in view of the above problems of the related art, and an object of the present invention is to provide a hot-rolled steel sheet having high strength and excellent shearing workability.

[0010] In the present invention, having excellent shearing workability indicates that a surface roughness R_z of a fractured surface at a sheared end surface after shearing is 30.0 μm or less. In addition, having high strength indicates that a tensile strength is 980 MPa or more.

[Means for Solving the Problem]

[0011] In view of the above problems, the present inventors obtained the following findings (a) to (d) as a result of intensive studies on a relationship between the chemical composition of the hot-rolled steel sheet and a microstructure, and mechanical properties, and completed the present invention.

[0012]

(a) In order to reduce a surface roughness of a fractured surface at a sheared end surface, it is necessary to limit an area fraction of ferrite having a high work hardening ability and an area fraction of pearlite which causes the formation of coarse voids.

(b) In order to reduce the surface roughness of the fractured surface at the sheared end surface, it is important to provide a microstructure in which coarse Ti-based carbides are present in a certain amount or more and a grain size is small. The reason for this is thought to be that the coarse Ti-based carbide is a carbide precipitated in an austenite structure during hot rolling. This coarse Ti-based carbide is incoherent with a primary phase which is transformed at a low temperature. Therefore, it is presumed that coarse and incoherent Ti-based carbides are dispersed and precipitated, and voids generated during shear deformation are dispersed, so that the surface roughness of the fractured surface is reduced in combination with the refinement of grains.

(c) In order to allow incoherent and coarse Ti-based carbide to be present in a certain amount or more, a hot rolling step in a high temperature range is important. For example, it is effective to perform hot rolling with a total rolling reduction of 70% or more in a temperature range of 1,100°C to SRT (°C).

(d) In order to reduce the grain size of the microstructure, it is important to increase a rolling reduction of hot rolling in a low temperature range while increasing the total rolling reduction in the high temperature range. For example, it is effective to perform hot rolling with a total rolling reduction of 80% or more in a temperature range from lower than 1,100°C to finishing of rolling. The refinement of the austenite structure is achieved by an austenite pinning effect due to the coarse Ti-based carbides precipitated in the high temperature range, and, as a result, a structure having a small grain size can be formed by the combination with the subsequent cooling conditions.

[0013] The gist of the present invention made based on the above findings is as follows.

[1] A hot-rolled steel sheet according to an aspect of the present invention includes, as a chemical composition, by mass%: C: 0.050% to 0.200%; Si: 0.005% to 2.000%; Mn: 0.50% to 4.00%; P: 0.100% or less; S: 0.0100% or less; sol. Al: 0.001% to 1.00%; Ti: 0.150 to 0.400%; N: 0.0010% to 0.0200%; Nb: 0% to 0.200%; V: 0% to 1.000%; Mo: 0% to 1.000%; Cu: 0% to 1.00%; Ni: 0% to 1.00%; Cr: 0% to 2.00%; W: 0% to 1.00%; B: 0% to 0.0040%; Ca: 0% to 0.0100%; Mg: 0% to 0.0100%; REM: 0% to 0.0100%; Bi: 0% to 0.0200%; and a remainder: Fe and impurities, in which, when a region of 1/8 to 3/8 of a sheet thickness in a sheet thickness direction from a surface is defined as a 1/4 depth position, a microstructure at the 1/4 depth position includes, by area fraction, retained austenite: less than 3.0%, ferrite: less than 30.0%, and pearlite: less than 5.0%, at the 1/4 depth position, an average number density of Ti-based carbides having a longest diameter of 15 nm or more is $1.0 \times 10^4 / \text{mm}^2$ or more, and an average grain size d_g is 15.0 μm or less, and a tensile strength is 980 MPa or more.

[2] In the hot-rolled steel sheet according to [1], when a region from the surface to 50 μm from the surface in the sheet thickness direction is defined as a surface layer portion, d_s/d_g , which is a ratio of an average grain size d_s of the surface layer portion to the average grain size d_g at the 1/4 depth position, may be 0.95 or less.

[3] In the hot-rolled steel sheet according to [1] or [2], the chemical composition may contain, by mass%, one or two or more selected from the group consisting of Nb: 0.001% to 0.200%, V: 0.005% to 1.000%, Mo: 0.001% to 1.000%, Cu: 0.02% to 1.00%, Ni: 0.02% to 1.00%, Cr: 0.02% to 2.00%, W: 0.020% to 1.00%, B: 0.0001% to 0.0040%, Ca: 0.0002% to 0.0100%, Mg: 0.0002% to 0.0100%, REM: 0.0002% to 0.0100%, and Bi: 0.0002% to 0.0200%

[Effects of the Invention]

[0014] According to the above aspect of the present invention, it is possible to obtain a hot-rolled steel sheet having high strength and excellent shearing workability.

[0015] The hot-rolled steel sheet according to the above aspect of the present invention is suitable as an industrial material used for vehicle members, mechanical structural members, and building members.

[Brief Description of the Drawings]

[0016] FIG. 1 is a diagram showing a sheared end surface after shearing.

[Embodiments of the Invention]

[0017] A hot-rolled steel sheet according to an embodiment of the present invention (the hot-rolled steel sheet according to the present embodiment) has a predetermined chemical composition, in which, when a region of 1/8 to 3/8 of a sheet thickness in a sheet thickness direction from a surface is defined as a 1/4 depth position, a microstructure at the 1/4 depth position includes, by area fraction, retained austenite: less than 3.0%, ferrite: less than 30.0%, and pearlite: less than 5.0%, at the 1/4 depth position, an average number density of Ti-based carbides having a longest diameter of 15

nm or more is 1×10^4 /mm² or more, and an average grain size d_g is 15.0 μ m or less, and a tensile strength is 980 MPa or more.

[0018] Features of the hot-rolled steel sheet according to the present embodiment (hereinafter, sometimes simply referred to as the steel sheet) will be more specifically described below. However, the present invention is not limited to configurations disclosed in the present embodiment, and various modifications can be made without departing from the gist of the present invention. The numerical limit range described below with "to" includes the lower limit and the upper limit. Numerical values indicated as "less than" or "more than" do not fall within the numerical range.

[Chemical Composition]

[0019] First, the chemical composition of the hot-rolled steel sheet according to the present embodiment will be described. In the following description, % regarding the chemical composition of the steel sheet is mass% unless particularly otherwise specified.

(C: 0.050% to 0.200%)

[0020] C is an element that increases a fraction of a hard phase, and increase strength of ferrite by being bonded to a precipitation-hardening element such as Ti, Nb, or V. When a C content is less than 0.050%, it is difficult to obtain a desired strength. Therefore, the C content is set to 0.050% or more. The C content is preferably 0.060% or more, more preferably 0.070% or more, and still more preferably 0.080% or more.

[0021] On the other hand, when the C content is more than 0.200%, weldability of the hot-rolled steel sheet decreases. Therefore, the C content is set to 0.200% or less. The C content is preferably 0.150% or less.

(Si: 0.005% to 2.000%)

[0022] Si is an element having an action of increasing strength of the hot-rolled steel sheet by solid solution strengthening. In addition, Si has an action of achieving soundness of steel by deoxidation (suppressing the occurrence of a defect such as a blowhole in steel). When a Si content is less than 0.005%, an effect by the above action cannot be obtained. Therefore, the Si content is set to 0.005% or more. The Si content is preferably 0.010% or more.

[0023] On the other hand, Si is an element having an action of deteriorating surface properties and chemical convertibility of the hot-rolled steel sheet and promoting the generation of retained austenite by suppressing the precipitation of cementite from austenite. When the Si content is more than 2.000%, retained austenite is generated, and a surface roughness of a fractured surface deteriorates. Therefore, the Si content is set to 2.000% or less. The Si content is preferably 1.500% or less, and more preferably 1.300% or less.

(Mn: 0.50% to 4.00%)

[0024] Mn is an element having an action of suppressing ferritic transformation and achieving high-strengthening of the hot-rolled steel sheet. When a Mn content is less than 0.50%, a tensile strength of 980 MPa or more cannot be obtained. Therefore, the Mn content is set to 0.50% or more. The Mn content is preferably 0.80% or more, and more preferably 1.00% or more. In addition, in a case where an area fraction of ferrite is reduced, the Mn content is still more preferably 1.40% or more, and even more preferably 1.50% or more.

[0025] On the other hand, when the Mn content is more than 4.00%, cracking occurs in the vicinity of a sheet thickness center due to center segregation of Mn, and a surface roughness of a sheared end surface after shearing deteriorates. Therefore, the Mn content is set to 4.00% or less. The Mn content is preferably 3.50% or less, and more preferably 3.00% or less.

(P: 0.100% or Less)

[0026] P is an element that is generally contained as an impurity. P is an element that is easily segregated, and when a P content is more than 0.100%, bending workability decreases due to boundary segregation. Therefore, the P content is set to 0.100% or less. The P content is preferably 0.030% or less.

[0027] A lower limit of the P content does not need to be particularly specified, but the P content is preferably set to 0.001% or more from the viewpoint of a refining cost. In addition, P is also an element having an action of increasing the strength of the hot-rolled steel sheet by solid solution strengthening. Therefore, P may be positively contained. Therefore, the P content may be set to 0.002% or more.

(S: 0.0100% or Less)

[0028] S is an element that is contained as an impurity and is an element that forms a sulfide-based inclusion in steel and decreases bending workability of the hot-rolled steel sheet. When a S content is more than 0.0100%, the bending workability of the hot-rolled steel sheet significantly decreases. Therefore, the S content is set to 0.0100% or less. The S content is preferably 0.0050% or less. A lower limit of the S content does not need to be particularly specified, but the S content preferably set to 0.0001% or more from the viewpoint of the refining cost.

(sol. Al: 0.001% to 1.00%)

[0029] Similar to Si, Al is an element having an action of deoxidizing steel and achieving soundness of steel. When a sol. Al content is less than 0.001%, an effect by the above action cannot be obtained. Therefore, the sol. Al content is set to 0.001% or more. The sol. Al content is preferably 0.01% or more.

[0030] On the other hand, when the sol. Al content is more than 1.00%, the above effects are saturated, which is economically undesirable. Therefore, the sol. Al content is set to 1.00% or less. The sol. Al content is preferably 0.80% or less, and more preferably 0.60% or less.

[0031] Here, sol. Al means acid-soluble Al, and indicates Al present in the steel in a solid solution state.

(Ti: 0.150% to 0.400%)

[0032] Ti is an element that precipitates as coarse Ti-based carbides in a high temperature range of hot rolling and reduces the surface roughness of the fractured surface in the sheared end surface. In addition, Ti is an element that suppresses recovery, recrystallization, and grain growth of an austenite structure and refines a microstructure after transformation. Furthermore, Ti is an element that precipitates as fine Ti-based carbides during cooling after hot rolling (after completion of finish rolling) and improves the strength of steel by precipitation hardening. When a Ti content is less than 0.150%, a driving force for the precipitation of the Ti-based carbides in a high temperature range of hot rolling is small, and a desired number density of Ti-based carbides cannot be obtained. Therefore, the Ti content is set to 0.150% or more. The Ti content is preferably 0.170% or more, more preferably 0.190% or more, and still more preferably 0.210% or more.

[0033] On the other hand, when the Ti content is more than 0.400%, coarse nitrides that are rectangular with a longest diameter of several μm in size are formed, and the bending workability decreases. Therefore, the Ti content is set to 0.400% or less. The Ti content is preferably 0.350% or less, and more preferably 0.300% or less.

[0034] The Ti-based carbide refers to a carbide having a NaCl-type crystal structure containing Ti. As long as such a carbide contains Ti, a small amount of other carbide-generating alloy elements such as Mo, Nb, V, Cr, and W are also contained in the range of the chemical composition specified in the present embodiment. In addition, carbonitrides in which some of carbon atoms are replaced with nitrogen atoms are also contained.

(N: 0.0010% to 0.0200%)

[0035] N is an element having an action of forming nitrides or carbonitrides with Ti, Nb, V, or the like and suppressing the coarsening of austenite during heating of a slab, thereby refining the microstructure. When a N content is less than 0.0010%, it becomes difficult to exhibit the above action. Therefore, the N content is set to 0.0010% or more. The N content is preferably 0.0015% or more.

[0036] On the other hand, when the N content is more than 0.0200%, coarse Ti nitrides are formed, and the bending workability decreases. Therefore, the N content is set to 0.0200% or less. The N content is preferably 0.0150% or less, more preferably 0.0100% or less, and still more preferably 0.0060% or less.

[0037] A remainder of the chemical composition of the hot-rolled steel sheet according to the present embodiment may be Fe and impurities. In the present embodiment, the impurities mean substances that are incorporated from ore as a raw material, scrap, a manufacturing environment, or the like and/or substances that are permitted to an extent that the hot-rolled steel sheet according to the present embodiment is not adversely affected.

[0038] On the other hand, the hot-rolled steel sheet according to the present embodiment may contain one or two or more of Nb, V, Mo, Cu, Ni, Cr, W, B, Ca, Mg, REM, and Bi as optional elements instead of a portion of Fe. Since it is not essential to contain the above optional elements, a lower limit of the amounts thereof is 0%. Hereinafter, the above optional elements will be described in detail.

(Nb: 0% to 0.200%)

[0039] Nb is an optional element. Nb is an element that has effects of precipitating in steel as a carbide, a nitride, a

EP 4 400 621 A1

carbonitride, or the like and increasing the tensile strength of the steel sheet. In order to obtain these effects, a Nb content is preferably set to 0.001% or more. The Nb content is more preferably 0.005% or more.

[0040] On the other hand, when the Nb content is more than 0.200%, the above effects are saturated, and there are cases where it is difficult to perform rolling due to an increase in rolling force during finish rolling. Therefore, in a case where Nb is contained, the Nb content is set to 0.200% or less. The Nb content is preferably 0.170% or less, more preferably 0.140% or less, and still more preferably 0.110% or less.

(V: 0% to 1.000%)

[0041] V is an optional element. V is an element that has effects of precipitating in steel as a carbide, a nitride, a carbonitride, or the like and improving the tensile strength of the steel sheet. In order to obtain these effects, a V content is preferably set to 0.005% or more. The V content is more preferably 0.010% or more.

[0042] On the other hand, when the V content is more than 1.000%, workability of the hot-rolled steel sheet decreases. Therefore, in a case where V is contained, the V content is set to 1.000% or less. The V content is more preferably 0.800% or less, and still more preferably 0.600% or less.

(Mo: 0% to 1.000%)

[0043] Mo is an optional element. Mo is an element that has effects of increasing hardenability of steel, forming a carbide or a carbonitride, and achieving high-strengthening of the steel sheet. In order to obtain these effects, a Mo content is preferably set to 0.001% or more. The Mo content is more preferably 0.005% or more.

[0044] On the other hand, when the Mo content is more than 1.000%, there are cases where susceptibility to cracking of slabs increases. Therefore, in a case where Mo is contained, the Mo content is set to 1.000% or less. The Mo content is more preferably 0.800% or less, and still more preferably 0.600% or less.

(Cu: 0% to 1.00%)

[0045] Cu is an optional element. Cu is an element having an effect of improving toughness of steel and an effect of increasing the tensile strength. In order to obtain these effects, a Cu content is preferably set to 0.02% or more. The Cu content is more preferably 0.08% or more.

[0046] On the other hand, when Cu is excessively contained, there are cases where the weldability of the steel sheet decreases. Therefore, in a case where Cu is contained, the Cu content is set to 1.00% or less. The Cu content is more preferably 0.50% or less, and still more preferably 0.30% or less.

(Ni: 0% to 1.00%)

[0047] Ni is an optional element. Ni has an effect of improving the toughness of steel and an effect of increasing the tensile strength. In order to obtain these effects, a Ni content is preferably set to 0.02% or more. The Ni content is more preferably 0.10% or more.

[0048] On the other hand, when Ni is excessively contained, an alloying cost is high, and there are cases where toughness of a welded heat-affected zone in the steel sheet deteriorates. Therefore, in a case where Ni is contained, the Ni content is set to 1.00% or less. The Ni content is more preferably 0.50% or less, and still more preferably 0.30% or less.

(Cr: 0% to 2.00%)

[0049] Cr is an optional element. Cr is an element that has effects of increasing the hardenability of steel, forming a carbide or a carbonitride, and achieving high-strengthening of the steel sheet. In order to obtain the effects, a Cr content is preferably set to 0.02% or more. The Cr content is more preferably 0.05% or more.

[0050] On the other hand, when Cr is excessively contained, the chemical convertibility deteriorates. Therefore, in a case where Cr is contained, the Cr content is set to 2.00% or less. The Cr content is more preferably 1.50% or less, still more preferably 1.00% or less, and particularly preferably 0.50% or less.

(W: 0% to 1.00%)

[0051] W is an optional element. W is an element having an effect of forming a carbide or a carbonitride and increasing the tensile strength. In order to obtain the effect, a W content is preferably set to 0.02% or more.

[0052] On the other hand, even if W is contained in a certain amount or more, the effect of the above action is saturated,

and the alloying cost increases. Therefore, in a case where W is contained, the W content is set to 1.00% or less. The W content is preferably 0.80% or less.

(B: 0% to 0.0040%)

[0053] B is an optional element. B is an element that has an effect of increasing the tensile strength of the steel sheet by grain boundary strengthening and solid solution strengthening. In order to obtain the effect, a B content is preferably set to 0.0001% or more. The B content is more preferably 0.0002% or more.

[0054] On the other hand, when the B content is more than 0.0040%, the effect is saturated, and the alloying cost increases. Therefore, in a case where B is contained, the B content is set to 0.0040% or less. The B content is more preferably 0.0030% or less, and still more preferably 0.0020% or less.

(Ca: 0% to 0.0100%)

[0055] Ca is an optional element. Ca is an element that has an effect of dispersing a number of fine oxides in molten steel to refine the microstructure of the steel sheet. In addition, Ca is an element that has an effect of improving stretch flangeability of the steel sheet by fixing S in molten steel as spherical CaS and suppressing the generation of an elongated inclusion such as MnS. In order to obtain these effects, a Ca content is preferably set to 0.0002% or more. The Ca content is more preferably 0.0005% or more.

[0056] On the other hand, when the Ca content is more than 0.0100%, the amount of CaO in steel increases, and there are cases where the toughness of the steel sheet is adversely affected. Therefore, in a case where Ca is contained, the Ca content is set to 0.0100% or less. The Ca content is more preferably 0.0050% or less, and still more preferably 0.0030% or less.

(Mg: 0% to 0.0100%)

[0057] Mg is an optional element. Similar to Ca, Mg is an element that has effects of suppressing the formation of coarse MnS by forming an oxide or a sulfide in molten steel and refining the microstructure of the steel sheet by dispersing a number of fine oxides. In order to obtain these effects, a Mg content is preferably set to 0.0002% or more. The Mg content is more preferably 0.0005% or more.

[0058] On the other hand, when the Mg content is more than 0.0100%, an oxide in steel increases, and the toughness of the steel sheet is adversely affected. Therefore, in a case where Mg is contained, the Mg content is set to 0.0100% or less. The Mg content is more preferably 0.0050% or less, and still more preferably 0.0030% or less.

(REM: 0% to 0.0100%)

[0059] REM is an optional element. Similar to Ca, REM is an element that also has effects of suppressing the formation of coarse MnS by forming an oxide or a sulfide in molten steel and refining the microstructure of the steel sheet by dispersing a number of fine oxides. In a case of obtaining these effects, a REM content is preferably set to 0.0002% or more. The REM content is more preferably 0.0005% or more.

[0060] On the other hand, when the REM content is more than 0.0100%, an oxide in steel increases, and there are cases where the toughness of the steel sheet is adversely affected. Therefore, in a case where REM is contained, the REM content is preferably set to 0.0100% or less. The REM content is more preferably 0.0050% or less, and still more preferably 0.0030% or less.

[0061] Here, REM (rare earth metal) refers to a total of 17 elements consisting of Sc, Y, and lanthanides. In the present embodiment, the REM content refers to the total amount of these elements.

(Bi: 0% to 0.0200%)

[0062] Bi is an optional element. Bi is an element that has an effect of improving formability of the steel sheet by refining a solidification structure. In order to obtain the effect, a Bi content is preferably set to 0.0001% or more. The Bi content is more preferably 0.0005% or more.

[0063] On the other hand, when the Bi content is more than 0.0200%, the above effect is saturated, and the alloying cost increases. Therefore, in a case where Bi is contained, the Bi content is set to 0.0200% or less. The Bi content is more preferably 0.0100% or less, and still more preferably 0.0070% or less.

[0064] The chemical composition of the above-described hot-rolled steel sheet may be measured by a general analytical method. For example, the chemical composition may be measured using inductively coupled plasma-atomic emission spectrometry (ICP-AES). sol. Al may be measured by ICP-AES using a filtrate obtained by heating and decomposing a

sample with an acid. C and S may be measured using a combustion-infrared absorption method, and N may be measured using an inert gas fusion-thermal conductivity method.

[Microstructure]

[0065] Next, the microstructure of the hot-rolled steel sheet according to the present embodiment will be described.

[0066] In the hot-rolled steel sheet according to the present embodiment, when a region of 1/8 to 3/8 of a sheet thickness from a surface is defined as a 1/4 depth position, a microstructure at the 1/4 depth position includes, by area fraction, less than 30.0% of ferrite, less than 3.0% of retained austenite, and less than 5.0% of pearlite. In addition, in the hot-rolled steel sheet according to the present embodiment, in the microstructure at the 1/4 depth position, an average grain size is 15.0 μm or less, an average number density of Ti-based carbides having a longest diameter of 15 nm or more is 1.0×10^4 /mm² or more (10,000 /mm² or more) (Ti-based carbide of 15 nm or more are precipitated in an average number density of 1.0×10^4 /mm² or more). The reason for specifying the microstructure in the region of 1/8 to 3/8 (1/4 depth position) of the sheet thickness from the surface of the steel sheet is that the microstructure at this position represents a typical microstructure of the steel sheet.

(Area Fraction of Ferrite: Less than 30.0%)

[0067] Ferrite is a structure generated when fcc transforms into bcc at a relatively high temperature. Since ferrite has a high work hardening ability, when the area fraction of ferrite is too large, the amount of deformation of the fractured surface at the sheared end surface increases, and the fractured surface roughness increases. Therefore, the area fraction of ferrite is set to less than 30.0%. The area fraction of ferrite is preferably 20.0% or less, more preferably 10.0% or less, and still more preferably 8.0% or less. The area fraction of ferrite is preferably as small as possible and may be 0%, but the area fraction of ferrite may be set to 1.0% or more, 2.0% or more, or 3.0% or more in consideration of productivity and the like.

(Area fraction of Retained Austenite: Less Than 3.0%)

[0068] In the hot-rolled steel sheet according to the present embodiment, when the area fraction of retained austenite is too large, there are cases where the surface roughness of the fractured surface at the sheared end surface increases. It is presumed that this is because retained austenite forms coarse voids. In particular, when the area fraction of retained austenite is 3.0% or more, shearing workability of the hot-rolled steel sheet deteriorates, and the surface roughness of the fractured surface increases. Therefore, the area fraction of retained austenite is set to less than 3.0%. The area fraction of retained austenite is preferably less than 1.5% and more preferably less than 1.0%. Since retained austenite is preferably as small as possible, the area fraction of retained austenite may be 0%.

(Area Fraction of Pearlite: Less than 5.0%)

[0069] Pearlite is a lamellar microstructure in which cementite is precipitated in layers between ferrite grains. In addition, pearlite is a soft microstructure compared to bainite and martensite. When the area fraction of pearlite is 5.0% or more, carbon is consumed by cementite contained in pearlite, and strengths of martensite, tempered martensite, and bainite, which are remaining structures, decrease, and a tensile strength of 980 MPa or more cannot be obtained. Therefore, the area fraction of pearlite is set to less than 5.0%. The area fraction of pearlite may be preferably 3.0% or less, more preferably 2.0%, still more preferably 1.0% or less, or 0%.

[0070] In the hot-rolled steel sheet according to the present embodiment, in order to secure a tensile strength of 980 MPa or more, the remaining structures other than retained austenite, ferrite, and pearlite preferably include one or two or more of bainite, martensite, and tempered martensite, which are hard structures. An area fraction of one or two or more of bainite, martensite, and tempered martensite is preferably 70.0% or more, more preferably 80.0% or more, and still more preferably 90.0% or more.

[0071] The area fraction of each structure forming the microstructure is measured by the following method. A sheet thickness cross section parallel to a rolling direction is mirror-finished and, furthermore, polished at room temperature with colloidal silica not containing an alkaline solution for 8 minutes, thereby removing strain introduced into a surface layer of a sample. At a random position of the sample cross section in a longitudinal direction, a region having a length of 50 μm from a depth of 1/8 of the sheet thickness from the surface to a depth of 3/8 of the sheet thickness from the surface is measured by electron backscatter diffraction at a measurement interval of 0.1 μm to obtain crystal orientation information. For the measurement, an EBSD apparatus including a thermal field-emission scanning electron microscope (JSM-7001F manufactured by JEOL Ltd.) and an EBSD detector (DVC5 type detector manufactured by TSL solutions) is used. In this case, a degree of vacuum in the EBSD apparatus is set to 9.6×10^{-5} Pa or less, an accelerating voltage

is set to 15 kV, an irradiation current level is set to 13, and an irradiation level of an electron beam is set to 62. Furthermore, a reflected electron image is taken in the same visual field. First, crystal grains where ferrite and cementite are precipitated in layers are specified from the reflected electron image, and the area fraction of the crystal grains is calculated, thereby obtaining the area fraction of pearlite. Thereafter, for crystal grains except the crystal grains determined to be pearlite,

from the obtained crystal orientation information, regions having a grain average misorientation value of 1.0° or less are determined to be ferrite using a "Grain Average Misorientation" function installed in software "OIM Analysis (registered trademark)" included in an EBSD analyzer. The area fraction of the regions determined to be ferrite is obtained, thereby obtaining the area fraction of ferrite.

[0072] Subsequently, under a condition in which a grain boundary of 5° or more is defined as a grain boundary in the remaining region (a region having a grain average misorientation value of more than 1.0°), when a maximum value of "Grain Average IQ" of a ferrite region is indicated as $I\alpha$, a region of more than $I\alpha/2$ is extracted as bainite, and a region of $I\alpha/2$ or less is extracted as "pearlite, martensite, and tempered martensite". The area fraction of bainite is obtained by calculating the area fraction of the extracted bainite. In addition, a sum of the area fractions of martensite and tempered martensite is obtained by calculating the area fractions of the extracted "pearlite, martensite, and tempered martensite" and subtracting the area fraction of pearlite obtained by the above EBSD analysis.

[0073] As a measurement method of the area fraction of retained austenite, there are methods by X-ray diffraction, electron back scattering diffraction pattern (EBSD) analysis, and magnetic measurement, and the like and measured values may differ depending on the measurement method. In the present embodiment, the area fraction of retained austenite is measured by X-ray diffraction.

[0074] In the measurement of the area fraction of retained austenite by X-ray diffraction in the present embodiment, the integrated intensities of a total of 6 peaks of $\alpha(110)$, $\alpha(200)$, $\alpha(211)$, $\gamma(111)$, $\gamma(200)$, and $\gamma(220)$ are obtained at a $1/4$ depth position (a region from a depth of $1/8$ of the sheet thickness from the surface to a depth of $3/8$ of the sheet thickness from the surface) of the hot-rolled steel sheet using Co-K α rays, and the area fraction of retained austenite is obtained by calculation using an intensity averaging method.

Average Number Density of Ti-Based Carbides Having Longest Diameter of 15 nm or More Is 1.0×10^4 /mm² or More)

[0075] In the hot-rolled steel sheet according to the present embodiment, coarse Ti-based carbides having a longest diameter of 15 nm or more are precipitated. Due to the presence of the coarse Ti-based carbides and the refinement of the average grain size described later, voids at the time of fracture in the shearing are dispersed, and the surface roughness of the fractured surface at the sheared end surface is reduced. For this, the average number density of Ti-based carbides having a longest diameter of 15 nm or more needs to be 1.0×10^4 (10,000) /mm² or more. The average number density of Ti-based carbides having a longest diameter of 15 nm or more is preferably 2.0×10^4 /mm² or more, and more preferably 4.0×10^4 /mm² or more. The average number density of Ti-based carbides having a longest diameter of 15 nm or more is preferably as large as possible, but may be set to 5.0×10^6 /mm² or less because there are cases where a decrease in the amount of solute C required for strengthening of fine Ti-based carbides, bainite, and martensite precipitated during cooling after the completion of hot rolling is incurred, resulting in a decrease in strength. Here, the Ti-based carbide refers to a carbide having a NaCl-type crystal structure containing Ti. As long as the carbide contains Ti, a small amount of other carbide-generating alloy elements may be contained. In the range of the chemical composition specified in the present embodiment, the Ti-based carbides may contain the other carbide-generating alloy elements such as Mo, Nb, V, Cr, and W. Furthermore, the Ti-based carbide may be a carbonitride in which some of carbon atoms are replaced with nitrogen atoms.

[0076] To obtain the average number density of the Ti-based carbides, 20 visual fields at the $1/4$ depth position are photographed at a magnification of 50,000-fold with transmission electron microscope (TEM) by setting a region of $2.0 \mu\text{m} \times 2.0 \mu\text{m}$ region as one visual field, precipitates observed in the visual fields are analyzed by energy dispersive X-ray spectroscopy (EDS), precipitates in which Ti and C are detected are determined to be Ti-based carbides, and a longest diameter of each of the precipitates (Ti-based carbide) is measured. Then, the number of Ti-based carbides having a longest diameter of 15 nm or more per 1 mm² is examined to obtain the number density.

(Average Grain Size: $15.0 \mu\text{m}$ or Less)

[0077] In the microstructure, when the average grain size is coarse, the fractured surface roughness of the sheared end surface increases. Therefore, the average grain size (dq) at the $1/4$ depth position is set to $15.0 \mu\text{m}$ or less. The average grain size is preferably $12.0 \mu\text{m}$ or less, and more preferably $10.0 \mu\text{m}$ or less. The average grain size is preferably as small as possible, and thus a lower limit thereof is not particularly limited. However, it is technically difficult to refine grains by normal hot rolling such that the average grain size becomes smaller than $1.0 \mu\text{m}$. Therefore, the average grain size may be set to $1.0 \mu\text{m}$ or more or $4.0 \mu\text{m}$ or more.

(Preferably, ds/dq , Ratio of Average grain size ds of Surface Layer Portion to Average grain size dq at 1/4 Depth Position: 0.95 or Less)

[0078] As the strength of the hot-rolled steel sheet increases, it is more likely that cracking occurs from the inside bend during bending (hereinafter, referred to as inside bend cracking). In particular, in a case where the tensile strength is 980 MPa or more as in the hot-rolled steel sheet according to the present embodiment, inside bend cracking is likely to occur.

[0079] The mechanism of the inside bend cracking is presumed as follows. That is, during bending, compressive stress is generated inside the bend. In the beginning, working proceeds while the entire inside of the bend is uniformly deformed; however, as the working amount increases, the deformation cannot proceed only with the uniform deformation, and deformation progresses with local concentration of strain (generation of a shear deformation band). As this shear deformation band further grows, cracks are initiated along the shear band from the surface of the inside of the bend and propagate.

[0080] It is presumed that the reason why the inside bend cracking is more likely to occur in association with high-strengthening is that a decrease in a work hardening ability caused by the high-strengthening makes deformation proceed non-uniformly, which generates a shear deformation band at an early stage of working (or under loose working conditions).

[0081] The present inventors examined a method for suppressing inside bend cracking in a high strength steel sheet. As a result, the present inventors found that, as the grain size of the surface layer portion of the hot-rolled steel sheet becomes finer, local strain concentration is further suppressed, and it becomes more unlikely that inside bend cracking occurs. More specifically, it was found that when a region from the surface to 50 μm in the sheet thickness direction from the surface (a region from the surface as a starting point to 50 μm in the sheet thickness direction from the surface) is defined as a surface layer portion, inside bend cracking is suppressed by setting ds/dq , which is a ratio of an average grain size ds of the surface layer portion of the hot-rolled steel sheet to an average grain size dq at the 1/4 depth position, to 0.95 or less. Therefore, in a case of obtaining a hot-rolled steel sheet having excellent bendability (suppressing inside bend cracking during bending) in addition to high strength and excellent shearing workability, ds/dq is preferably set to 0.95 or less. ds/dq is more preferably 0.90 or less, and still more preferably 0.85 or less. A lower limit of ds/dq is not particularly specified and may be set to 0.50 or more.

[0082] To obtain the average grain size of each of the surface layer portion and the 1/4 depth position, in a sheet thickness cross section parallel to the rolling direction of the hot-rolled steel sheet, each of the surface layer portion of the hot-rolled steel sheet (a region from the surface to a position at a depth of 50 μm from the surface) and the 1/4 depth position (a region from a depth of 1/8 of the sheet thickness from the surface to a depth of 3/8 of the sheet thickness from surface) is analyzed and measured using EBSD in at least five visual fields at a magnification of 1,200-fold by setting a region of 40 $\mu\text{m} \times 30 \mu\text{m}$ as one visual field. Regarding the measurement, a region where an angle difference between adjacent measurement points is 15° or more and a circle equivalent diameter is 0.3 μm or more is defined as a grain boundary, and an area-averaged grain size is calculated. The area-averaged grain sizes obtained at the individual measurement positions are regarded as the average grain size of the surface layer portion and the average grain size at the 1/4 depth position.

<Mechanical Properties>

(Tensile Strength: 980 MPa or More)

[0083] The hot-rolled steel sheet according to the present embodiment has a tensile (maximum) strength of 980 MPa or more. When the tensile strength is less than 980 MPa, an applicable component is limited, and the contribution to a reduction in weight of a vehicle body is small. The tensile strength is preferably 1,000 MPa or more, more preferably 1,080 MPa or more, and still more preferably 1,180 MPa or more. An upper limit does not need to be particularly limited, but the tensile strength may be set to 1,780 MPa or less from the viewpoint of suppressing wearing of a die.

[0084] The tensile strength of the hot-rolled steel sheet is evaluated according to JIS Z 2241: 2011. A No. 5 test piece of JIS Z 2241: 2011 is used as a test piece, and a test direction is set to a direction perpendicular to the rolling direction.

[0085] The sheet thickness of the hot-rolled steel sheet according to the present embodiment is not particularly limited and may be set to 1.2 to 10.0 mm. When the sheet thickness of the hot-rolled steel sheet is less than 1.2 mm, it is difficult to secure a rolling completion temperature, a rolling force becomes excessive, and there are cases where it is difficult to perform hot rolling. Therefore, the sheet thickness of the hot-rolled steel sheet according to the present embodiment may be set to 1.2 mm or more. The sheet thickness is more preferably 1.4 mm or more. On the other hand, when the sheet thickness is more than 10.0 mm, it becomes difficult to refine the microstructure, and there are cases where it is difficult to obtain the above-described microstructure. Therefore, the sheet thickness may be set to 10.0 mm or less. The sheet thickness is more preferably 8.0 mm or less. The sheet thickness is still more preferably 6.0 mm or less.

<Manufacturing Conditions>

[0086] A manufacturing method of the hot-rolled steel sheet according to the present embodiment is not particularly limited, but the hot-rolled steel sheet can be obtained by a manufacturing method including the following steps.

- (I) A heating step of heating a slab or a steel piece having a predetermined chemical composition.
- (II) A hot rolling step of performing multi-pass hot rolling on the slab or the steel piece after the heating step using a plurality of rolling stands to obtain a hot-rolled steel sheet.
- (III) A coiling step of coiling the hot-rolled steel sheet.

[0087] Hereinafter, preferable conditions for each step will be described.

[Heating Step]

(Heating Temperature: Higher Than 1,300°C and Equal To or Higher Than SRT (°C))

[0088] A heating temperature of the slab or the steel piece that is to be subjected to hot rolling is set to be higher than 1,300°C and equal to or higher than a temperature SRT (°C) represented by Expression (1). In normal hot rolling, heating to a temperature of higher than 1,300°C is considered undesirable because a yield decreases due to a mass loss of iron caused by oxides in a heating furnace and surface defects are generated due to melting of scale. However, in order to obtain coarse Ti-based carbides having a desired number density as in the hot-rolled steel sheet according to the present embodiment, the Ti-based carbides need to be sufficiently solutionized in the heating step. Therefore, the slab or the steel piece that is to be subjected to hot rolling is heated so as to have a temperature of higher than 1,300°C and equal to or higher than SRT (°C). Here, the expression "the temperature of the slab or the steel piece is higher than 1,300°C and equal to or higher than SRT (°C)" means that the temperature of the slab or the steel piece is higher than the higher of 1,300°C or SRT (°C), or, in a case where SRT (°C) is higher than 1,300°C, SRT and the temperature of the slab or the steel piece are the same.

[0089] On the other hand, when the heating temperature is higher than 1,400°C, there are cases where a thick scale is generated, resulting in a decrease in yield or significant damage to the heating furnace. Therefore, the heating temperature is preferably 1,400°C or lower.

$$SRT\ (^{\circ}C) = 1,630 + 90 \times \ln([C] \times [Ti]) \dots (1)$$

[0090] Here, [element symbol] in Expression (1) indicates the amount of each element in the slab or the steel piece by mass%. $\ln$ is a natural logarithm.

[0091] The slab or the steel piece to be heated may be a slab or a steel piece obtained by continuous casting or casting and blooming or may be also a slab or a steel piece obtained by additionally performing hot working or cold working on the above-described slab or steel piece. A chemical composition of the slab or the steel piece does not substantially change in the manufacturing process and thus may be the same as the chemical composition of the desired hot-rolled steel sheet.

[Hot Rolling Step]

[0092] In the hot rolling step, multi-pass hot rolling is performed on the heated slab or steel piece using a plurality of rolling stands to manufacture a hot-rolled steel sheet. The multi-pass hot rolling can be performed using a reverse mill or a tandem mill, and, from the viewpoint of industrial productivity, a tandem mill is preferably used in at least several stands from the end.

(Total Rolling Reduction in Temperature Range of 1,100°C or Higher and SRT (°C) or Lower: 70% or More)

[0093] In the manufacturing method of the hot-rolled steel sheet according to the present embodiment, a total rolling reduction of hot rolling in a temperature range of 1,100°C or higher and SRT (°C) or lower is increased to achieve refinement of recrystallized austenite and to precipitate coarse Ti-based carbides having a longest diameter of 15 nm or more within a short period of time in a limited time during rolling by strain-induced precipitation. In a case where the total rolling reduction in this temperature range is small, it becomes difficult to obtain a fine structure or a desired Ti-based carbide. Specifically, in order to achieve the refinement of recrystallized austenite and obtain a desired Ti-based carbide, the total rolling reduction in a temperature range of 1,100°C or higher and SRT (°C) or lower is set to 70% or

more. When the total rolling reduction in the above temperature range is less than 70%, a desired coarse Ti-based carbide cannot be obtained. The total rolling reduction is preferably 75% or more, and more preferably 80% or more. The total rolling reduction in the temperature range of 1, 100°C or higher and SRT (°C) or lower is preferably as large as possible.

(Total Rolling Reduction in Temperature Range of Lower Than 1,100°C and Hot Rolling Completion Temperature FT (°C) or Higher: 80% or Higher)

[0094] In the manufacturing method of the hot-rolled steel sheet according to the present embodiment, after the rolling reduction in a temperature range of 1,100°C or higher is controlled as described above, a total rolling reduction in a temperature range of lower than 1,100°C and FT (°C) or higher is increased and cooling is further performed after the hot rolling under conditions described later, thereby refining the average grain size.

[0095] When the total rolling reduction in the temperature range of lower than 1,100°C and FT (°C) or higher is less than 80%, the average grain size after transformation becomes coarse. Therefore, the total rolling reduction in the temperature range of lower than 1,100°C and FT (°C) or higher is set to 80% or more. The total rolling reduction is preferably 85% or more, and more preferably 90% or more. The total rolling reduction in the temperature range of lower than 1,100°C and FT (°C) or higher is preferably as high as possible, but may be set to 99% or less because an industrial limit is approximately 99%.

[0096] In order to refine the average grain size, it is important to refine an austenite structure by repeating working and recrystallization in both of the rolling in the temperature range of 1,100°C or higher and SRT (°C) or lower, and the rolling in the temperature range of lower than 1, 100°C and FT°C or higher. Therefore, two or more passes of rolling are performed in each temperature range.

[0097] The total rolling reduction in each temperature range in the hot rolling step refers to a percentage of, with respect to an inlet sheet thickness before an initial pass in a predetermined temperature range, a total rolling reduction amount in this temperature range (a difference between the inlet sheet thickness before the initial pass of rolling in this temperature range and an outlet sheet thickness after a final pass of rolling in this temperature range).

(Hot Rolling Completion Temperature FT (°C): Ar3 (°C) or Higher Obtained by Expression (2))

[0098] When FT is lower than Ar3 (°C), ferritic transformation proceeds during finish rolling, coarse ferrite grains are partially or almost entirely generated, and the shearing workability decreases. Therefore, the FT is set to Ar3 (°C) or higher.

[0099] On the other hand, even if FT is higher than 1,050°C, the shearing workability decreases due to the coarsening of the structure. Therefore, FT is set to 1,050°C or lower. FT is preferably 1,030°C or lower, and more preferably 1,010°C or lower.

[0100] The temperature during the hot rolling refers to a surface temperature of steel and can be measured using a radiation-type thermometer or the like.

$$\text{Ar3 (}^\circ\text{C)} = 901 - 325 \times [\text{C}] + 33 \times [\text{Si}] - 92 \times [\text{Mn}] + 287 \times [\text{P}] + 40 \times [\text{sol.Al}]$$

[0101] Here, [element symbol] in Expression (2) indicates the amount of each element by mass%, and 0 is assigned in a case where the element is not contained.

(Average Cooling Rate to 600°C or Lower After Completion of Hot Rolling: 50 °C/sec or Faster)

(Preferably, Cooling to Temperature of Hot Rolling Completion Temperature FT - 50°C or Lower within 1.0 Seconds after Completion of Hot Rolling)

[0102] After the completion of the hot rolling, accelerated cooling is performed to a temperature range of 600°C or lower at an average cooling rate of 50 °C/sec or faster in order to suppress the generation of ferrite and pearlite.

[0103] The average cooling rate referred herein is a value obtained by dividing a temperature drop width of the steel sheet from the start of accelerated cooling (when the steel sheet is introduced into a cooling facility) to the completion of accelerated cooling (when the steel sheet is taken out of the cooling facility) by the time required from the start of accelerated cooling to the completion of accelerated cooling.

[0104] An upper limit of the average cooling rate is not particularly specified, but an increase in the cooling rate causes an increase in size of the cooling facility and an increase in facility cost. Therefore, considering the facility cost, the average cooling rate is preferably 300 °C/sec or slower.

[0105] In addition, in the cooling after the hot rolling, it is more preferable to perform cooling by 50°C or more within

1.0 second after the completion of the hot rolling (set a temperature drop allowance to 50°C or more) in order to suppress the growth of austenite grains refined by the hot rolling. In order to perform cooling to a temperature range of the hot rolling completion temperature FT - 50°C or lower within 1.0 second after the completion of the hot rolling, cooling is performed at a fast average cooling rate immediately after the completion of the hot rolling. For example, the cooling water may be sprayed to the surface of the steel sheet. By performing cooling to the temperature range of FT - 50°C or lower within 1.0 second after the completion of the hot rolling, the grain size of the surface layer portion can be refined and inside bend cracking resistance can be increased (the occurrence of inside bend cracking during bending is suppressed).

(Stay Time in Temperature Range of 600°C to 750°C: 5.0 Seconds or Shorter)

[0106] In order to suppress the generation of ferrite and pearlite and obtain a tensile strength of 980 MPa or more by making a primary phase structure hard, a stay time in a temperature range of 600°C to 750°C, which is a ferritic transformation temperature range, is preferably set to 5.0 seconds or shorter. The stay time in the temperature range of 600°C to 750°C is more preferably 2.0 seconds or shorter.

[Coiling Step]

(Coiling temperature: Lower Than 600°C)

[0107] The hot-rolled steel sheet that has been cooled under the above conditions is coiled. A coiling temperature (which is substantially equal to a cooling stop temperature) is set to be in a temperature range of lower than 600°C. By setting the coiling temperature to be in this temperature range, a bainite or martensite structure can be obtained. In addition, by suppressing the grain growth after coiling, it is possible to obtain a fine structure with high strength, and as a result, excellent shearing workability can be obtained.

[0108] In the manufacturing method of the hot-rolled steel sheet according to the present embodiment, the structures and a precipitation state of carbides are controlled in steps up to the coiling step. Therefore, it is preferable not to perform a step that affects the structure or the state of the carbides after the coiling step.

[Examples]

[0109] Next, effects of one aspect of the present invention will be more specifically described using examples, but conditions in the examples are simply examples of the conditions adopted to confirm the feasibility and effects of the present invention, and the present invention is not limited to these examples of the conditions. The present invention can adopt various conditions as long as the object of the present invention is achieved without departing from the gist of the present invention.

[0110] Steels having the chemical composition shown in Table 1 were melted and continuously cast to manufacture slabs having a thickness of 240 to 300 mm. The obtained slabs were used to obtain hot-rolled steel sheets shown in Tables 3A and 3B under the manufacturing conditions shown in Tables 2A and 2B. In any of the rolling in the temperature range of 1,100°C or higher and SRT (°C) or lower and the rolling in the temperature range of lower than 1,100°C and FT°C or higher, two or more passes of reduction were performed.

[0111] Using the above-described method, for the obtained hot-rolled steel sheet, at a 1/4 depth position, area fractions of microstructures, an average number density of Ti-based carbides having a longest diameter of 15 nm or more, and an average grain size, and ds/dq, which is a ratio of an average grain size ds of a surface layer to an average grain size dq at the 1/4 depth position of a sheet thickness from the surface were obtained. The obtained measurement results are shown in Tables 3A and 3B.

[0112] In addition, a tensile strength TS, shearing workability, and inside bend cracking resistance were evaluated for the obtained hot-rolled steel sheets in the following manner.

[Tensile Properties]

[0113] The tensile strength of the hot-rolled steel sheet was evaluated according to JIS Z 2241: 2011. A No. 5 test piece of JIS Z 2241: 2011 was used as a test piece, and a test direction was set to a direction perpendicular to the rolling direction.

[0114] In a case where the tensile strength TS was 980 MPa or more, the hot-rolled steel sheet was considered to have high strength and determined to be acceptable. On the other hand, in a case where the tensile strength TS was less than 980 MPa, the hot-rolled steel sheet was considered to be poor in strength and determined to be unacceptable.

[Shearing Workability]

[0115] The shearing workability of the hot-rolled steel sheet was evaluated by obtaining a surface roughness R_z (μm) of a fractured surface at an end surface after punching by a punching test.

[0116] Punched holes were prepared with a hole diameter of 10 mm, a punching speed of 3 m/s, a clearance of 20%. Next, the surface roughness R_z (μm) of the fractured surface of the end surface was measured at a total of four points in a rolling direction and in a rolling orthogonal direction of the punched holes using a laser microscope, and evaluation was performed with the maximum value thereof.

[0117] In a case where R_z was 30.0 μm or less, the hot-rolled steel sheet was determined to be excellent in shearing workability. As shown in FIG. 1, the fractured surface is a punched end surface separated by a crack initiated from the vicinity of a cutting edge after the end of the shear deformation.

[Inside Bend Cracking Resistance]

[0118] The inside bend cracking resistance was evaluated by the following bending test.

[0119] A 100 mm $\times$ 30 mm strip-shaped test piece was cut out from the hot-rolled steel sheet to obtain a bending test piece. For both a bend where a bending ridge was parallel to the rolling direction (L direction) (L-axis bending) and a bend where a bending ridge was parallel to a direction perpendicular to the rolling direction (C direction) (C-axis bending), inside bend cracking resistance was investigated according to JIS Z 2248: 2014 (V block 90° bending test), and minimum bend radii at which cracks were not initiated were obtained. A value obtained by dividing an average value of the minimum bend radii in the L axis and in the C axis by the sheet thickness was regarded as a limit bend R/t and used as an index value of inside bend cracking resistance. In a case where R/t was 2.5 or less, the hot-rolled steel sheet was determined to be excellent in inside bend cracking resistance.

[0120] Here, regarding the presence or absence of cracks, a cross section obtained by cutting the test piece after the V block 90° bending test on a surface parallel to the bending direction and perpendicular to the sheet surface was mirror polished, cracks were then observed with an optical microscope, and a case where lengths of cracks observed on an inside of the bend of the test piece was more than 30 μm was determined as cracks being present.

[0121] The obtained results are shown in Tables 3A and 3B.

[Table 1]

Steel	(mass%: remainder includes Fe and impurities)																				SRT	Ar3
	C	Si	Mn	P	S	sol. Al	Ti	N	Nb	V	Mo	Cu	Ni	Cr	W	B	Ca	Mg	REM	Bi	(°C)	(°C)
A	0.065	0.016	1.65	0.010	0.0058	0.05	0.210	0.0029	0.059												1244	733
B	0.054	0.856	2.48	0.008	0.0057	0.03	0.156	0.0026													1200	687
C	0.110	0.935	2.06	0.011	0.0024	0.07	0.211	0.0036	0.028												1291	713
D	0.114	0.956	2.02	0.011	0.0040	0.05	0.210	0.0032	0.030	0.205						0.0012	0.0015				1294	715
E	0.125	0.914	2.10	0.011	0.0009	0.09	0.212	0.0039	0.025	0.281						0.0015					1303	704
F	0.120	0.102	3.20	0.008	0.0021	0.03	0.283	0.0034													1326	574
G	0.115	0.034	2.45	0.009	0.0052	0.06	0.211	0.0045													1295	644
H	0.110	0.042	2.50	0.009	0.0012	0.05	0.278	0.0032		0.110											1316	641
I	0.108	0.063	2.49	0.014	0.0002	0.06	0.231	0.0034			0.06	0.04									1298	645
J	0.110	0.025	2.44	0.010	0.0027	0.09	0.211	0.0037					0.20								1291	648
K	0.114	0.025	2.42	0.010	0.0027	0.09	0.220	0.0037						0.05							1298	649
L	0.111	0.079	2.46	0.016	0.0020	0.03	0.215	0.0044									0.0022				1294	647
M	0.112	0.368	2.51	0.010	0.0027	0.04	0.245	0.0037								0.0015					1306	650
N	0.111	0.032	2.47	0.016	0.0018	0.06	0.254	0.0029										0.0025			1309	646
O	0.107	0.025	2.48	0.010	0.0024	0.04	0.234	0.0030											0.0023		1298	643
P	0.113	0.039	2.50	0.010	0.0019	0.08	0.241	0.0038												0.0015	1306	642
Q	0.112	0.060	2.61	0.015	0.0032	0.36	0.251	0.0021		0.210		0.10	0.06				0.0020			0.0018	1309	645
R	0.125	0.246	2.35	0.012	0.0021	0.05	0.225	0.0025	0.020	0.235	0.104										1309	658
S	0.041	0.209	2.53	0.014	0.0017	0.07	0.256	0.0030													1220	669
T	0.111	2.156	2.47	0.016	0.0006	0.08	0.232	0.0041													1301	717
U	0.111	0.498	2.50	0.016	0.0006	0.08	0.138	0.0041													1254	659
V	0.071	0.422	0.40	0.013	0.0019	0.08	0.210	0.0045													1251	862

EP 4 400 621 A1

[Table 2A]

Test No.	Steel	Heating temperature (°C)	Total rolling reduction in temperature range of 1,100°C or higher and SRT (°C) or lower (%)	Total rolling reduction in temperature range of lower than 1,100°C and FT (°C) or higher (%)	Hot rolling completion temperature FT (°C)	Cooling amount within 1.0 second after completion of hot rolling (°C)	Average cooling rate to 600°C or lower after completion of hot rolling (°C/sec)	Stay time from 600°C to 750°C (sec)	Coiling temperature (°C)
1	A	1372	83	93	886	21	87	1.8	474
2	A	1357	82	90	894	57	80	1.9	554
3	A	1353	75	90	895	59	85	1.8	489
4	A	1377	83	82	897	67	71	2.0	501
5	A	1377	83	92	897	67	71	2.2	< 50
6	A	1235	71	91	861	63	74	2.0	588
7	A	1354	64	90	879	56	77	2.1	514
8	A	1359	85	75	870	70	58	2.7	501
9	A	1355	83	93	893	25	32	6.9	510
10	A	1379	80	92	870	56	75	2.0	651
11	B	1359	81	91	869	73	72	2.2	504
12	C	1372	82	92	897	58	75	2.2	505
13	D	1375	85	90	897	73	77	2.1	552
14	E	1362	80	93	868	62	80	1.9	542
15	F	1354	80	93	862	56	87	1.9	540

[Table 2B]

Test No.	Steel	Heating temperature (°C)	Total rolling reduction in temperature range of 1,100°C or higher and SRT (°C) or lower (%)	Total rolling reduction in temperature range of lower than 1,100°C and FT (°C) or higher (%)	Hot rolling completion temperature FT (°C)	Cooling amount within 1.0 second after completion of hot rolling (°C)	Average cooling rate to 600°C or lower after completion of hot rolling (°C/sec)	Stay time from 600°C to 750°C (sec)	Coiling temperature (°C)
16	G	1351	81	93	877	66	88	1.7	499
17	H	1351	83	91	881	61	71	2.3	514
18	I	1368	82	94	907	64	76	2.0	585
19	J	1356	81	92	876	66	79	2.0	527
20	K	1374	85	92	872	57	81	1.9	488
21	L	1354	81	93	866	73	68	2.4	536
22	M	1360	82	91	868	58	83	2.0	484
23	N	1357	83	92	866	68	78	2.0	558
24	O	1364	85	93	886	64	81	2.0	571

EP 4 400 621 A1

(continued)

Test No.	Steel	Heating temperature (°C)	Total rolling reduction in temperature range of 1,100°C or higher and SRT (°C) or lower (%)	Total rolling reduction in temperature range of lower than 1,100°C and FT (°C) or higher (%)	Hot rolling completion temperature FT (°C)	Cooling amount within 1.0 second after completion of hot rolling (°C)	Average cooling rate to 600°C or lower after completion of hot rolling (°C/sec)	Stay time from 600°C to 750°C (sec)	Coiling temperature (°C)
25	P	1378	81	92	897	62	82	2.0	485
26	Q	1377	83	92	875	61	72	2.2	527
27	R	1367	84	92	870	62	72	2.1	479
28	<u>S</u>	1358	84	92	872	66	74	2.2	524
29	<u>T</u>	1365	81	92	876	56	81	1.9	526
30	<u>U</u>	1352	80	92	888	57	68	2.3	564
31	<u>V</u>	1380	82	93	898	67	80	2.1	484

[Table 3A]

Test No.	Steel	Microstructure							Properties			Remarks
		Area ratio of ferrite (%)	Area ratio of retained austenite (%)	Area ratio of pearlite (%)	Total area ratio of bainite, martensite, and tempered martensite (%)	Average number density of Ti-based carbides having longest diameter of 15 nm or more (/mm ²)	Average grain size (μm)	ds/dq	TS (MPa)	Surface roughness Rz of fractured surface (μm)	Limit bend R/t	
1	A	5.9	0.1	0.0	94.0	51601	8.8	0.97	1001	14.9	2.8	Invention Example
2	A	7.8	0.2	0.0	92.0	49429	9.0	0.88	1032	152	2.5	Invention Example
3	A	6.5	0.1	0.0	93.4	29083	10.1	0.87	1045	18.9	2.5	Invention Example
4	A	4.2	0.5	0.0	95.3	50331	10.5	0.83	1013	16.4	2.4	Invention Example
5	A	9.3	0.5	0.0	90.2	50331	5.0	0.83	1149	11.3	2.4	Invention Example
6	A	8.0	0.0	0.0	92.0	8043	11.3	0.79	1021	31.0	2.3	Comparative Example
7	A	8.3	0.0	0.0	91.7	4434	13.2	0.87	1029	38.0	2.5	Comparative Example
8	A	15.1	0.1	1.5	83.3	54200	15.5	0.85	990	32.5	2.4	Comparative Example
9	A	34.1	0.1	0.0	65.8	51911	16.8	0.98	945	32.3	3.0	Comparative Example
10	A	86.5	0.0	0.0	13.5	49115	12.5	0.84	914	35.2	2.4	Comparative Example
11	B	6.5	0.8	0.0	92.7	34479	7.8	0.75	1174	15.8	2.2	Invention Example
12	C	7.2	1.9	0.0	90.9	51980	5.2	0.87	1167	114	2.5	Invention Example

(continued)

Test No.	Steel	Microstructure							Properties			Remarks
		Area ratio of ferrite (%)	Area ratio of retained austenite (%)	Area ratio of pearlite (%)	Total area ratio of bainite, martensite, and tempered martensite (%)	Average number density of Ti-based carbides having longest diameter of 15 nm or more (/mm ²)	Average grain size (μm)	ds/dq	TS (MPa)	Surface roughness Rz of fractured surface (μm)	Limit bend R/t	
13	D	2.5	2.1	0.0	95.4	54781	8.1	0.82	1224	14.0	2.4	Invention Example
14	E	1.5	2.4	0.0	96.1	51068	5.9	0.79	1267	12.2	2.3	Invention Example
15	F	4.5	0.1	0.0	95.4	69852	5.0	0.82	1277	10.2	2.4	Invention Example

[Table 3B]

Test No.	Steel	Microstructure							Properties			Remarks
		Area ratio of ferrite (%)	Area ratio of retained austenite (%)	Area ratio of pearlite (%)	Total area ratio of bainite, martensite, and tempered martensite (%)	Average number density of Ti-based carbides having longest diameter of 15 nm or more (/mm ²)	Average grain size (μm)	ds/dq	TS (MPa)	Surface roughness Rz of fractured surface (μm)	Limit bend R/t	
16	G	4.8	0.2	0.0	95.0	48838	6.6	0.78	1189	13.1	2.3	Invention Example
17	H	7.5	0.1	0.0	92.4	68389	5.6	0.84	1209	10.9	2.4	Invention Example
18	I	7.1	0.0	0.0	92.9	55234	5.0	0.84	1190	11.0	2.4	Invention Example
19	J	5.6	0.0	0.0	94.4	51147	6.5	0.79	1210	12.8	2.3	Invention Example
20	K	6.3	0.1	0.0	93.6	54066	5.3	0.84	1184	11.4	2.4	Invention Example
21	L	7.8	0.2	0.0	92.0	52528	6.0	0.72	1188	12.2	2.1	Invention Example
22	M	2.1	0.1	0.0	97.8	56986	5.4	0.83	1203	11.3	2.4	Invention Example
23	N	7.2	0.1	0.0	92.7	65172	5.3	0.76	1188	10.8	2.2	Invention Example
24	O	6.8	0.0	0.0	93.2	56518	5.5	0.81	1186	11.4	2.3	Invention Example
25	P	6.0	0.0	0.0	94.0	56539	6.2	0.85	1193	12.1	2.4	Invention Example
26	Q	7.2	0.1	0.0	92.7	61493	5.2	0.82	1216	10.8	2.4	Invention Example
27	R	6.5	0.0	0.0	93.5	54653	5.4	0.80	1219	11.5	2.3	Invention Example

(continued)

Test No.	Steel	Microstructure							Properties			Remarks
		Area ratio of ferrite (%)	Area ratio of retained austenite (%)	Area ratio of pearlite (%)	Total area ratio of bainite, martensite, and tempered martensite (%)	Average number density of Ti-based carbides having longest diameter of 15 nm or more (/mm ²)	Average grain size (μm)	ds/dq	TS (MPa)	Surface roughness Rz of fractured surface (μm)	Limit bend R/t	
28	<u>S</u>	7.5	0.0	0.0	92.5	67835	7.6	0.79	<u>923</u>	20.5	2.3	Comparative Example
29	<u>I</u>	6.7	<u>4.1</u>	0.0	89.2	54550	5.9	0.85	1247	31.5	2.4	Comparative Example
30	<u>U</u>	8.1	0.2	0.0	91.7	<u>2341</u>	10.5	0.86	1204	41.1	2.5	Comparative Example
31	<u>V</u>	5.7	0.1	0.0	94.2	64067	6.9	0.82	<u>942</u>	15.8	2.4	Comparative Example

[0122] As can be seen from Tables 1 to 3B, it can be seen that the hot-rolled steel sheets (Test Nos. 1 to 5 and 11 to 27) according to present invention examples are found to have excellent strength and shearing workability. In addition, it can be seen that among the present invention examples, the hot-rolled steel sheets where ds/dq was 0.95 or less had the above properties and further had excellent inside bend cracking resistance.

[0123] On the other hand, it can be seen that the hot-rolled steel sheets according to comparative examples did not have any one or more of excellent strength and shearing workability.

[0124] In Test No. 6 as a comparative example, the heating temperature of the slab was low. Therefore, the Ti-based carbides were not sufficiently solutionized during heating, and the average number density of Ti-based carbides having a longest diameter of 15 nm or more decreased. As a result, the roughness of the fractured surface became rough (the shearing workability was low).

[0125] In Test No. 7 as a comparative example, the total rolling reduction in the temperature range of 1,100°C or higher and SRT (°C) or lower was small. Therefore, the average number density of Ti-based carbides having a longest diameter of 15 nm or more decreased. As a result, the roughness of the fractured surface became rough.

[0126] In Test No. 8 as a comparative example, the total rolling reduction in the temperature range of lower than 1,100°C and FT (°C) or higher was small. Therefore, the average grain size increased. As a result, the roughness of the fractured surface became rough.

[0127] In Test No. 9 as a comparative example, after the completion of the hot rolling, the average cooling rate to 600°C or lower was slow, and the stay time at 600°C to 750°C was long. Therefore, the area fraction of ferrite increased, and the average grain size increased. As a result, the tensile strength was low, and the roughness of the fractured surface became rough. In addition, ds/dq was high and the inside bend cracking resistance was also low.

[0128] In Test No. 10 as a comparative example, the coiling temperature was high. Therefore, the area fraction of ferrite was high. As a result, the tensile strength was low, and the roughness of the fractured surface became rough.

[0129] In Test No. 28 as a comparative example, the C content was low. As a result, the tensile strength was low.

[0130] In Test No. 29 as a comparative example, the Si content was high. As a result, the area of retained austenite increased, and the roughness of the fractured surface became rough.

[0131] In Test No. 30 as a comparative example, the Ti content was low. Therefore, the average number density of Ti-based carbides having a longest diameter of 15 nm or more decreased. As a result, the roughness of the fractured surface became rough.

[0132] In Test No. 31 as a comparative example, the Mn content was low. As a result, the tensile strength was low.

[Industrial Applicability]

[0133] According to the present invention, it is possible to obtain a hot-rolled steel sheet having high strength and excellent shearing workability. The hot-rolled steel sheet according to the present invention is suitable as an industrial material used for vehicle members, mechanical structural members, and building members, and has high industrial applicability.

Claims

1. A hot-rolled steel sheet comprising, as a chemical composition, by mass%:

C: 0.050% to 0.200%;
 Si: 0.005% to 2.000%;
 Mn: 0.50% to 4.00%;
 P: 0.100% or less;
 S: 0.0100% or less;
 sol. Al: 0.001% to 1.00%;
 Ti: 0.150 to 0.400%;
 N: 0.0010% to 0.0200%;
 Nb: 0% to 0.200%;
 V: 0% to 1.000%;
 Mo: 0% to 1.000%;
 Cu: 0% to 1.00%;
 Ni: 0% to 1.00%;
 Cr: 0% to 2.00%;
 W: 0% to 1.00%;
 B: 0% to 0.0040%;

EP 4 400 621 A1

Ca: 0% to 0.0100%;
Mg: 0% to 0.0100%;
REM: 0% to 0.0100%;
Bi: 0% to 0.0200%; and

a remainder: Fe and impurities,
wherein, when a region of 1/8 to 3/8 of a sheet thickness in a sheet thickness direction from a surface is defined as a 1/4 depth position, a microstructure at the 1/4 depth position includes, by area fraction,

retained austenite: less than 3.0%,
ferrite: less than 30.0%, and
pearlite: less than 5.0%,

at the 1/4 depth position,

an average number density of Ti-based carbides having a longest diameter of 15 nm or more is 1.0×10^4 /mm² or more, and
an average grain size dq is 15.0 μm or less, and

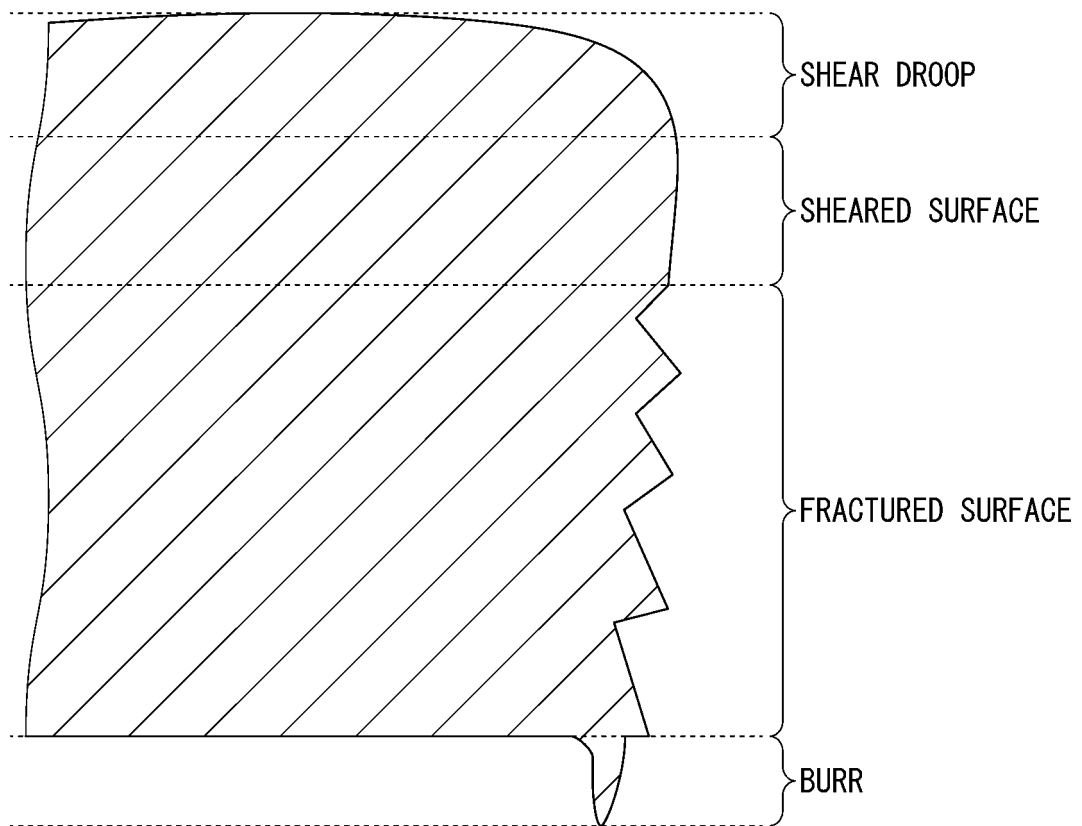
a tensile strength is 980 MPa or more.

2. The hot-rolled steel sheet according to claim 1,
wherein, when a region from the surface to 50 μm from the surface in the sheet thickness direction is defined as a surface layer portion, ds/dq, which is a ratio of an average grain size ds of the surface layer portion to the average grain size dq at the 1/4 depth position, is 0.95 or less.

3. The hot-rolled steel sheet according to claim 1 or 2, wherein the chemical composition contains, by mass%, one or two or more selected from the group consisting of

Nb: 0.001 % to 0.200%,
V: 0.005% to 1.000%,
Mo: 0.001% to 1.000%,
Cu: 0.02% to 1.00%,
Ni: 0.02% to 1.00%,
Cr: 0.02% to 2.00%,
W: 0.020% to 1.00%,
B: 0.0001% to 0.0040%,
Ca: 0.0002% to 0.0100%,
Mg: 0.0002% to 0.0100%,
REM: 0.0002% to 0.0100%, and
Bi: 0.0002% to 0.0200%.

FIG. 1



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2022/033730

A. CLASSIFICATION OF SUBJECT MATTER <i>C22C 38/00</i> (2006.01)i; <i>C21D 9/46</i> (2006.01)i; <i>C22C 38/58</i> (2006.01)i FI: C22C38/00 301W; C22C38/58; C21D9/46 T 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) C22C38/00-38/60; C21D9/46 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Published examined utility model applications of Japan 1922-1996 Published unexamined utility model applications of Japan 1971-2022 Registered utility model specifications of Japan 1996-2022 Published registered utility model applications of Japan 1994-2022 Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)									
C. DOCUMENTS CONSIDERED TO BE RELEVANT <table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>A</td> <td>WO 2019/009410 A1 (NIPPON STEEL & SUMITOMO METAL CORP) 10 January 2019 (2019-01-10)</td> <td>1-3</td> </tr> <tr> <td>A</td> <td>WO 2021/124864 A1 (NIPPON STEEL CORP) 24 June 2021 (2021-06-24)</td> <td>1-3</td> </tr> </tbody> </table>	Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	A	WO 2019/009410 A1 (NIPPON STEEL & SUMITOMO METAL CORP) 10 January 2019 (2019-01-10)	1-3	A	WO 2021/124864 A1 (NIPPON STEEL CORP) 24 June 2021 (2021-06-24)	1-3
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.							
A	WO 2019/009410 A1 (NIPPON STEEL & SUMITOMO METAL CORP) 10 January 2019 (2019-01-10)	1-3							
A	WO 2021/124864 A1 (NIPPON STEEL CORP) 24 June 2021 (2021-06-24)	1-3							
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Date of the actual completion of the international search 17 November 2022	Date of mailing of the international search report 29 November 2022								
Name and mailing address of the ISA/JP Japan Patent Office (ISA/JP) 3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915 Japan	Authorized officer Telephone No.								

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/033730

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