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(54) **HIGH-STRENGTH HOT-ROLLED STEEL SHEET AND METHOD FOR PRODUCING SAME**
HOCHFESTES HEISSGEWALZTES STAHLBLECH UND VERFAHREN ZU SEINER HERSTELLUNG
TÔLE EN ACIER LAMINÉE À CHAUD HAUTEMENT RÉSISTANTE, ET PROCÉDÉ DE FABRICATION
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Description**TECHNICAL FIELD**

[0001] The present invention relates to a high-strength hot-rolled steel sheet that has both high strength, or a tensile strength (TS) of 980 MPa or more, and excellent workability (particularly, bending workability), and is usefully applied in automobile members, and a method for producing the same.

BACKGROUND ART

[0002] In recent years, to reduce CO₂ emission from the viewpoint of global environment protection, there is an increasing demand in the entire automobile industry for improved fuel efficiency of automobiles. To improve fuel efficiency of automobiles, it is most effective to reduce the weight of automobiles by reducing the thickness of members used in the automobiles. Accordingly, high-strength hot-rolled steel sheets have been increasingly used as materials for automobile components. On the other hand, since most of automobile members made by steel sheets are formed by press forming or the like, the steel sheets for automobile components are required to have high strength as well as excellent bendability (bending workability).

[0003] In general, however, ductility and workability are reduced as steel materials have higher strength. This may cause difficulties in forming a steel sheet with enhanced strength of an increased tensile strength of 980 MPa or more into the desired shape of components. For example, in the case where a steel sheet having a tensile strength of 980 MPa or more is subjected to press forming, it is difficult to form the steel sheet into the shape of components due to significant cracking, necking, and so on occurring at bending-processed portions.

[0004] For the reasons noted above, it has been desired to develop a high-strength steel sheet that exhibits both desired strength and excellent bending workability when applied to automobile components or the like, and various techniques have been proposed to date.

[0005] For example, JP 2007-262429 A (PTL 1) proposes a technique where a steel sheet is arranged to have a chemical composition containing, in mass%, C: 0.05 % to 0.20 % and Nb: 0.1 % to 1.0 %, and that the content of solute C is 0.03 % or less. According to the technique proposed by PTL 1, it is said that by limiting the content of solute C by a chemical system containing Nb and C, such an abrasion-resistant steel sheet is obtained that has microstructures in which the matrix is ferrite phase which is soft in nature, and NbC is dispersed in the matrix as a hard secondary phase, and that have excellent bending workability.

[0006] In addition, JP 2008-189978 A (PTL 2) proposes a technique whereby a steel sheet is arranged to have a chemical composition containing, in mass%, C: 0.02 % to 0.2 %, Si: 0.01 % to 1.0 %, Mn: 0.1 % to 2.0 %, P: 0.2 % or less, sol. Al: 0.001 % to 0.5 %, Ti: 0.1 % or less, Nb: 0.1 % or less, V: 0.5 % or less, Mo: 0.5 % or less, and Ti + Nb: 0.1 % or less, and have microstructures with ferrite as the main phase, where an average grain size of ferrite within a region from a surface of the steel sheet to a 1/4 depth of the thickness of the steel sheet and an increasing rate of the average grain size at 700 °C are defined. It is stated in the technique proposed by PTL 2 that a steel sheet having excellent workability is obtained.

CITATION LIST**Patent Literature**

[0007]

PTL 1: JP 2007-262429 A

PTL 2: JP 2008-189978 A

SUMMARY OF INVENTION**(Technical Problem)**

[0008] However, the technique proposed by PTL 1 involves substantially enhancing the strength of a steel sheet by dispersing NbC, and it is difficult to obtain a steel sheet having a tensile strength of 980 MPa or more by using this technique utilizing NbC. This is because while the degree of precipitation strengthening achieved by dispersing precipitates increases with increasing carbide volume fraction, it is not possible to increase the carbide volume fraction due to a small solubility product in steel and a large atomic density of NbC.

[0009] In addition, in the technique proposed by PTL 2, Ti and V are added to steel as precipitation-strengthening

elements, but Ti and V for forming carbides are contained in the steel in a small amount, or added to the steel in an inappropriate manner, in which case, again, the tensile strength of the steel sheet does not reach 980 MPa.

[0010] As described above, in the conventional techniques, it was difficult to obtain a high-strength steel sheet having a tensile strength of 980 MPa or more. Moreover, it was not possible to impart excellent bending workability to the steel sheet, while retaining such high strength of the steel sheet.

[0011] The present invention has been made in view of these situations, and an object of the present invention is to provide a high-strength hot-rolled steel sheet that has a tensile strength of 980 MPa or more, and still exhibits excellent bending workability.

(Solution to Problem)

[0012] To solve the aforementioned problems, the inventors of the present invention have focused on a technique for enhancing the strength of a ferrite single-phase steel sheet having good workability by achieving fine particle distribution of carbides therein, and made intensive studies on various factors that have an effect on enhancement of the strength of the steel sheet and workability, particularly bending workability, of the steel sheet.

[0013] Then, the inventors have found that for the purpose of obtaining a hard, ferrite single-phase steel sheet from the ferrite phase that would normally be soft in nature, it is extremely helpful to allow fine particle distribution of carbides in the ferrite phase, and, as a result of search for elements that allow precipitation of a large amount of fine carbides, titanium (Ti) was identified as the most suitable element for this purpose.

[0014] However, since it was difficult to provide a ferrite single-phase, hot-rolled steel sheet with a tensile strength as high as 980 MPa or more by using Ti carbides alone, the inventors of the present invention have searched for ways to reinforce dispersion and precipitation strengthening by means of Ti carbides.

[0015] As a result, the inventors have conceived an idea of adding vanadium (V) as reinforcing means. It is hard for V to precipitate when added alone due to its high solubility in steel, whereas it becomes easier for V to precipitate when coupled with Ti carbides. As a result, when Ti and V are added in combination to the steel material of the hot-rolled steel sheet in an appropriate amount, the strength of the steel sheet is dramatically increased as compared to the case where Ti or V is added alone, whereby a hot-rolled steel sheet having a tensile strength of 980 MPa or more is obtained.

[0016] It was also found to be important to contain Ti in an amount equal to or more than the content of V since precipitation of V is facilitated when coupled with Ti carbides.

[0017] In addition, the inventors of the present invention have searched for ways to impart excellent bending workability to a high-strength hot-rolled steel sheet having a tensile strength of 980 MPa or more, to which Ti and V have been added in combination as described above, while maintaining the strength of the steel sheet. As a result, to give bending workability, it was found necessary to improve the surface appearance quality of the steel sheet, and furthermore, reduce solute elements that would deteriorate the workability of the steel sheet and reduce inclusions as much as possible that would serve as the origins of voids. As a result of further investigations, it was revealed that a hot-rolled steel sheet that has a tensile strength of 980 MPa or more and exhibits excellent bending workability may be obtained by arranging the steel sheet to have a component composition with optimized contents of C, Mn, Ti and V, while reducing Si content as much as possible.

[0018] The present invention has been completed based on the aforementioned discoveries and the primary features thereof are as follows.

[1] A high-strength hot-rolled steel sheet having excellent bendability, the steel sheet comprising a chemical composition consisting of, in mass%,

C: 0.06 % or more and 0.1 % or less,

Si: 0.09 % or less,

Mn: 0.7 % or more and 1.3 % or less,

P: 0.03 % or less,

S: 0.01 % or less,

Al: 0.1 % or less,

N: 0.01 % or less,

Ti: 0.14 % or more and 0.20 % or less,

V: 0.07 % or more and 0.14 % or less, optionally Nb: 0.01 % or more and 0.05 % or less, optionally at least one of Mo: 0.05 % or less, W: 0.05 % or less, Zr: 0.05 % or less, and Hf: 0.05 % or less, optionally at least one of O (oxygen), Se, Te, Po, As, Bi, Ge, Pb, Ga, In, Tl, Zn, Cd, Hg, Ag, Au, Pd, Pt, Co, Rh, Ir, Ru, Os, Tc, Re, Ta, Be, Sr, REM, B, Ni, Cr, Sb, Cu, Sn, Mg, and Ca, in a total amount of 0.2 % or less, and

the balance being Fe and incidental impurities,

wherein the steel sheet has microstructures such that an area ratio of ferrite phase is 95 % or more, an average grain size of the ferrite phase is 8 μm or less, and carbides in grains of the ferrite phase have an average particle

size of less than 10 nm, and

wherein the steel sheet has a tensile strength of 980 MPa or more.

[2] The high-strength hot-rolled steel sheet having excellent bendability according to [1] above, wherein the chemical composition contains, in mass%, Nb: 0.01 % or more and 0.05 % or less.

[3] The high-strength hot-rolled steel sheet having excellent bendability according to [1] or [2] above, wherein the chemical composition contains at least one of Mo, W, Zr and Hf, the content of each element being controlled so that Mo: 0.05 % or less, W: 0.05 % or less, Zr: 0.05 % or less, and Hf: 0.05 % or less.

[4] The high-strength hot-rolled steel sheet having excellent bendability according to any one of [1] to [3] above, wherein the chemical composition contains, in mass%, at least one of O (oxygen), Se, Te, Po, As, Bi, Ge, Pb, Ga, In, Tl, Zn, Cd, Hg, Ag, Au, Pd, Pt, Co, Rh, Ir, Ru, Os, Tc, Re, Ta, Be, Sr, REM, B, Ni, Cr, Sb, Cu, Sn, Mg, and Ca, in a total amount of 0.2 % or less.

[5] The high-strength hot-rolled steel sheet having excellent bendability according to any one of [1] to [4] above, further comprising a plating layer on a surface of the steel sheet.

[6] The high-strength hot-rolled steel sheet having excellent bendability according to [5] above, wherein the plating layer is a galvanized layer.

[7] The high-strength hot-rolled steel sheet having excellent bendability according to [5] above, wherein the plating layer is a galvanized layer.

[8] A method of producing a high-strength hot-rolled steel sheet having excellent bendability, comprising: heating a steel material; subjecting the steel material to hot rolling including rough rolling and finish rolling; and after completion of the finish rolling, cooling and coiling thus rolled steel material to gain a hot-rolled steel sheet, wherein the steel material has a chemical composition consisting of, in mass%,

C: 0.06 % or more and 0.1 % or less,

Si: 0.09 % or less,

Mn: 0.7 % or more and 1.3 % or less,

P: 0.03 % or less,

S: 0.01 % or less,

Al: 0.1 % or less,

N: 0.01 % or less,

Ti: 0.14 % or more and 0.20 % or less,

V: 0.07 % or more and 0.14 % or less, optionally Nb: 0.01 % or more and 0.05 % or less, optionally at least one of Mo: 0.05 % or less, W: 0.05 % or less, Zr: 0.05 % or less, and Hf: 0.05 % or less, optionally at least one of O (oxygen), Se, Te, Po, As, Bi, Ge, Pb, Ga, In, Tl, Zn, Cd, Hg, Ag, Au, Pd, Pt, Co, Rh, Ir, Ru, Os, Tc, Re, Ta, Be, Sr, REM, B, Ni, Cr, Sb, Cu, Sn, Mg, and Ca, in a total amount of 0.2 % or less, and

the balance being Fe and incidental impurities, and

wherein the steel material is heated at a temperature of 1100 °C or higher and 1350 °C or lower, the finish rolling is operated at a finish rolling temperature of 850 °C or higher, the cooling is initiated within 3 seconds after completion of the finish rolling, the cooling is operated at an average cooling rate of 20 °C/s or higher, and the coiling is operated at a coiling temperature of 550 °C or higher and 700 °C or lower.

[9] The method of producing a high-strength hot-rolled steel sheet having excellent bendability according to [8] above, wherein the chemical composition contains, in mass%, Nb: 0.01 % or more and 0.05 % or less.

[10] The method of producing a high-strength hot-rolled steel sheet having excellent bendability according to [8] or [9] above, wherein the chemical composition contains at least one of Mo, W, Zr and Hf, the content of each element being controlled so that Mo: 0.05 % or less, W: 0.05 % or less, Zr: 0.05 % or less, and Hf: 0.05 % or less.

[11] The method of producing a high-strength hot-rolled steel sheet having excellent bendability according to any one of [8] to [10] above, wherein the chemical composition contains, in mass%, at least one of O (oxygen), Se, Te, Po, As, Bi, Ge, Pb, Ga, In, Tl, Zn, Cd, Hg, Ag, Au, Pd, Pt, Co, Rh, Ir, Ru, Os, Tc, Re, Ta, Be, Sr, REM, B, Ni, Cr, Sb, Cu, Sn, Mg, and Ca, in a total amount of 0.2 % or less.

[12] The method of producing a high-strength hot-rolled steel sheet having excellent bendability according to any one of [8] to [11] above, comprising forming a plating layer on a surface of the hot-rolled steel sheet.

[13] The method of producing a high-strength hot-rolled steel sheet having excellent bendability according to [12] above, wherein the plating layer is a galvanized layer.

[14] The method of producing a high-strength hot-rolled steel sheet having excellent bendability according to [12] above, wherein the plating layer is a galvanized layer.

(Advantageous Effect of Invention)

[0019] According to the present invention, it is possible to obtain a high-strength hot-rolled steel sheet having a tensile strength of 980 MPa or more and excellent bending workability that is suitably applicable to automobile structural members or the like, that is highly advantageous in, for example, being capable of reducing the weight of automobile members, forming automobile members or the like, and that enables the even wider application of high-strength hot-rolled steel sheets, thereby causing a significantly advantageous effect in industrial terms.

DESCRIPTION OF EMBODIMENTS

[0020] The present invention will be described in detail below.

(High-strength hot-rolled steel sheet)

[0021] Firstly, description will be made on limitations on the microstructures and carbides of the steel sheet of the present invention. The hot-rolled steel sheet of the present invention has microstructures such that an area ratio of ferrite phase is 95 % or more, an average grain size of the ferrite phase is 8 μm or less, and carbides in grains of the ferrite phase have an average particle size of less than 10 nm.

Area ratio of ferrite phase: 95 % or more

[0022] The metal structure of the matrix of the hot-rolled steel sheet is preferably ferrite single-phase structure having excellent workability. When a secondary phase, such as bainite phase, martensite phase, cementite or pearlite, is incorporated into the microstructures of the steel sheet, voids are generated at interfaces between the ferrite phase and the secondary phase having different hardness from each other, which deteriorates the bending workability of the steel sheet.

[0023] In addition, the present invention allows carbides, such as Ti and/or V carbides, to precipitate in the steel sheet in order to ensure the desired strength of the steel sheet. Most of these carbides are such carbides that undergo austenite to ferrite transformation and interphase precipitation at the same time during a cooling step after completion of the finish rolling in the process of producing a hot-rolled steel sheet. Thus, it is necessary to facilitate ferrite transformation to obtain more carbides for the desired strength (tensile strength: 980 MPa or more) of the steel sheet; if the area ratio of the ferrite phase is below 95 %, it is difficult to ensure a tensile strength of 980 MPa or more.

[0024] For the reasons given above, it is preferable in the present invention that the metal structure of the hot-rolled steel sheet is ferrite single-phase structure. However, if the metal structure is not exact ferrite single phase, it is still possible to obtain the desired strength (tensile strength: 980 MPa or more) as long as the ferrite area ratio is 95 % or more. Therefore, the area ratio of the ferrite phase is to be 95 % or more, preferably 98 % or more.

[0025] In addition, in the hot-rolled steel sheet of the present invention, typical phases other than the ferrite phase that may be contained in the steel sheet include cementite, pearlite, bainite, martensite, and so on. If such phases are present in the steel sheet in a large amount, the properties (such as bending workability) of the steel sheet deteriorate. It is thus preferable to reduce such phases as much as possible, although a total area ratio of these phases is acceptable up to 5 %, and is preferably 2 % or less, relative to the entire metal structure of the steel sheet.

Average grain size of ferrite phase: 8 μm or less

[0026] A ferrite average grain size exceeding 8 μm more likely results in mixed-grain-size microstructures. Then, in such mixed-grain-size microstructures, coarse ferrite grains are more susceptible to stress concentration during bending working, which leads to a significant reduction in the bending workability of the steel sheet. Accordingly, the upper limit of the average grain size of the ferrite phase is to be 8 μm . The average grain size of the ferrite phase is preferably 6 μm or less, more preferably 4.5 μm or less.

Carbides in ferrite grains

[0027] From the viewpoint of ensuring strength, the hot-rolled steel sheet of the present invention must allow fine precipitation of carbides in the grains of the ferrite phase. In the present invention, the carbides to be finely precipitated in the grains of the ferrite phase include Ti carbides, V carbides, composite carbides of Ti and V and carbides further containing Nb, W, Mo, Hf and Zr. Most of these carbides are such carbides that undergo austenite to ferrite transformation and interphase precipitation at the same time during a cooling step after completion of the finish rolling in the process of producing a hot-rolled steel sheet.

Average particle size of carbides in the ferrite grains: less than 10 nm

[0028] In the hot-rolled steel sheet of the present invention, the above-described fine dispersion of carbides, mainly of composite carbides of Ti and V, is used to enhance the strength of the steel sheet, where finer carbides provide more particles interfering with dislocation movement, and hence result in a higher degree of enhancement of the strength achieved by the dispersion of the carbides. Accordingly, in the present invention, for the purpose of providing the hot-rolled steel sheet with the desired tensile strength (980 MPa), the average particle size of the carbides to be dispersed in the ferrite grains is to be less than 10 nm, preferably less than 7 nm, more preferably 5 nm or less.

[0029] Next, description will be made on reasons for limitations on the chemical composition of the hot-rolled steel sheet of the present invention. As used herein, "%" in the following chemical compositions means "mass%," unless otherwise specified.

$$0.06 \% \leq C \leq 0.1 \%$$

[0030] Carbon (C) is bonded to Ti, V or further to Nb to form carbides, which present with fine particle distribution in the steel sheet. That is, C is an element that forms fine carbides to significantly strengthen the ferrite phase and is essential for enhancing the strength of a hot-rolled steel sheet. To obtain a high-strength steel sheet having a tensile strength of 980 MPa or more, C content in steel needs to be at least 0.06 % or more. On the other hand, C content in steel exceeding 0.1 % causes precipitation of a large amount of cementite, which deteriorates the bending workability of the steel sheet. This is because micro-voids are generated more easily at interfaces between cementite and the matrix (ferrite), and these micro-voids constitute a factor in causing cracks in the steel sheet at those portions subjected to bending working. Accordingly, the C content is to be 0.06 % or more and 0.1 % or less, preferably 0.07 % or more and 0.09 % or less.

$$Si \leq 0.09 \%$$

[0031] Silicon (Si) has been intentionally contained in conventional high-strength steel sheets as an element that effectively improves the strength of the steel sheets without deteriorating the ductility (elongation). However, Si tends to be concentrated on surfaces of the steel sheets and form fayalite (Fe_2SiO_4) thereon. Since the fayalite is formed in wedge shape on a surface of the steel sheet, it would serve as the origin of cracking when the steel sheet is being subjected to bending working. Accordingly, it is desirable in the present invention to reduce Si content in steel as much as possible; however, up to 0.09 % is acceptable and the upper limit of the Si content is to be 0.09 %. The Si content is preferably 0.06 % or less. The Si content may be reduced to impurity level.

$$0.7 \% \leq Mn \leq 1.3 \%$$

[0032] Manganese (Mn) is an element that serves to refine carbides to be precipitated in grains of the ferrite phase of a hot-rolled steel sheet, and thus effectively enhances the strength of the steel sheet. As described earlier, in the present invention, most of these carbides precipitated in the grains of the ferrite phase will undergo austenite to ferrite transformation and interphase precipitation at the same time during a cooling step after completion of the finish rolling in the process of producing a hot-rolled steel sheet. Thus, if the transformation occurs at a high temperature, carbides would be precipitated at a high temperature range and experience coarsening during the cooling step arriving at coiling.

[0033] To address these problems, since Mn has an effect of lowering the temperature at which austenite to ferrite transformation occurs in steel, the transformation temperature may be lowered to a coiling temperature range described later by containing a predetermined amount of Mn, and carbides may be precipitated concurrently with coiling of the steel sheet. Then, such carbides precipitated concurrently with the coiling without being exposed at a high temperature range for a long period of time would be kept in fine grain condition. To obtain a hot-rolled steel sheet having a tensile strength of 980 MPa or more by refining carbides, Mn content in steel needs to be at least 0.7 % or more. On the other hand, Mn content in steel exceeding 1.3 % leads to a significant deterioration in the workability of the steel sheet due to solute Mn, which makes it impossible to obtain the desired bending workability. Accordingly, the Mn content is to be 0.7 % or more and 1.3 % or less, preferably 0.8 % or more and 1.2 % or less.

$$P \leq 0.03 \%$$

[0034] Phosphorus (P) is a harmful element that serves as the origin of intergranular cracking during working when segregated at grain boundaries and thereby deteriorates the bending workability of the steel sheet. It is thus preferable to reduce P content in steel as much as possible. Accordingly, to avoid this problem, the P content is to be 0.03 % or less, preferably 0.02 % or less in the present invention. The P content may be reduced to impurity level.

$$S \leq 0.01 \%$$

[0035] Sulfur (S) is present in steel as inclusions, such as MnS. Since such inclusions are hard in nature, interfaces between the matrix and the inclusions serve as the origins of voids when the steel sheet is being subjected to bending working, which results in a deterioration in the bending workability of the steel sheet. Accordingly, it is preferable in the present invention to reduce S content as much as possible. The S content is to be 0.01 % or less, preferably 0.008 % or less. The S content may be zero, in which case there is no problem.

$$Al \leq 0.1 \%$$

[0036] Aluminum (Al) is an element that functions as a deoxidizer. To obtain this effect, Al is desirably contained in steel in an amount of 0.02 % or more. However, if Al content exceeds 0.1 %, the adverse effect on the bending workability caused by inclusions, such as alumina, appears. Accordingly, the Al content is to be 0.1 % or less, preferably 0.08 % or less.

$$N \leq 0.01 \%$$

[0037] Nitrogen (N) is an element that is bonded to Ti, which is a carbide-forming element, to form coarse Ti nitrides at the steelmaking stage and inhibits formation of fine carbides, which results in a significant deterioration in the strength of the steel sheet. Moreover, when the steel sheet is being subjected to bending working, voids are generated more easily at interfaces between the matrix and coarse Ti nitrides, which adversely affects the bending workability of the steel sheet. Accordingly, it is preferable to reduce N content as much as possible. The N content is to be 0.01 % or less, preferably 0.008 % or less. The N content may be zero, in which case there is no problem.

$$0.14 \% \leq Ti \leq 0.20 \%$$

[0038] Titanium (Ti) is an element that is bonded to C to form carbides and thereby contributes to enhancing the strength of the steel sheet. To ensure the desired strength (tensile strength: 980 MPa or more) of the hot-rolled steel sheet, Ti content needs to be 0.14 % or more. On the other hand, if Ti content in steel exceeds 0.20 % in producing a hot-rolled steel sheet, coarse Ti carbides may not be dissolved by heating the steel material (slab) prior to hot rolling, which results in coarse Ti carbides remaining in the finally obtained (coiled) hot-rolled steel sheet. Such coarse Ti carbides left in the steel sheet reduce the strength of the hot-rolled steel sheet, and even more, interfaces between the matrix and the coarse Ti carbides serve as the origins of voids when the steel sheet is being subjected to bending working, which results in a deterioration in the bending workability of the steel sheet. Accordingly, the Ti content is to be 0.14 % or more and 0.20 % or less, preferably 0.15 % or more and 0.19 % or less.

$$0.07 \% \leq V \leq 0.14 \%$$

[0039] Vanadium (V) is an element that is bonded to C to form carbides and thereby contributes to enhancing the strength of the steel sheet, as is the case with Ti. V is bonded to Ti to form fine composite carbides, and thus is effective for enhancing the strength of the steel sheet. To ensure the desired strength (tensile strength: 980 MPa or more) of the hot-rolled steel sheet, V content needs to be 0.07 % or more. On the other hand, if V content is larger than the Ti content, it is difficult to allow V to precipitate, in which case more V would remain in the steel sheet in solute state. Since V in solute state leads to a deterioration in the bending workability of the steel sheet, the V content needs to be equal to or smaller than the Ti content, i.e., 0.14 % or less. Accordingly, the V content is to be 0.07 % or more and 0.14 % or less, preferably 0.08 % or more and 0.13 % or less.

$$0.01 \% \leq \text{Nb} \leq 0.05 \%$$

[0040] In addition to the aforementioned basic components, the composition of the steel sheet of the present invention may further contain Nb: 0.01 % or more and 0.05 % or less.

[0041] Niobium (Nb) is an element that acts to inhibit recrystallization of austenite grains before transforming from austenite to ferrite and thereby provide non-recrystallized structure in the hot rolling step in producing a hot-rolled steel sheet having substantially ferrite single-phase structure. As the non-recrystallized structure is more prone to storage of strain energy caused by hot rolling, there are more nucleation sites for ferrite phase. Thus, addition of Nb may increase the number of nucleation sites for ferrite phase in the hot rolling step, which enables refinement of grains of the ferrite phase. To obtain this effect, Nb content is preferably 0.01 % or more. However, if excessive strain energy is applied to the steel in the hot rolling step, the temperature at which austenite to ferrite transformation occurs is raised, in which case fine carbides may not be obtained. In view of this, Nb content is preferably 0.05 % or less, more preferably 0.02 % or more and 0.04 % or less.

$$\text{Mo} \leq 0.05 \%, \text{W} \leq 0.05 \%, \text{Zr} \leq 0.05 \%, \text{Hf} \leq 0.05 \%$$

[0042] In addition to the aforementioned basic components, the composition of the steel sheet of the present invention may further contain at least one of molybdenum (Mo), tungsten (W), zirconium (Zr) and hafnium (Hf), in which case the content of each element is preferably controlled so that Mo: 0.05 % or less, W: 0.05 % or less, Zr: 0.05 % or less, and Hf: 0.05 % or less. Mo, W, Zr and Hf are elements that form carbides contributing to enhancing the strength of the steel sheet; however, they remain in the steel sheet in solute state in a large amount. These solute elements deteriorate the workability of the matrix and adversely affect the bending workability of the steel sheet. Mo, W, Zr and Hf precipitate at a low rate relative to their contents and remain in the steel sheet as solute elements in a large amount. Accordingly, it is desirable to reduce the contents of these elements as much as possible; however the content of each of these elements is acceptable up to 0.05 %, and thus the upper limit of each element is to be 0.05 %. Preferably, the content of each element is 0.03 % or less. Also, the contents of Mo, W, Zr and Hf may be zero.

Other possible elements

[0043] In addition to the aforementioned basic components, the composition of the steel sheet of the present invention may further contain at least one of O (oxygen), Se, Te, Po, As, Bi, Ge, Pb, Ga, In, Ti, Zn, Cd, Hg, Ag, Au, Pd, Pt, Co, Rh, Ir, Ru, Os, Tc, Re, Ta, Be, Sr, REM, B, Ni, Cr, Sb, Cu, Sn, Mg, and Ca, in a total amount of 0.2 % or less. From the viewpoint of the bending workability of the steel sheet, acceptable contents of these elements are up to 0.2 % in total, preferably not more than 0.09 % in total. The balance, or components other than those described above, of the composition of the steel sheet is Fe and incidental impurities.

[0044] In addition, a plating layer may also be formed on a surface of the hot-rolled steel sheet of the present invention. Formation of such a plating layer on the surfaces improves the corrosion resistance property of the hot-rolled steel sheet, and thereby makes the steel sheet applicable to components such as automobile components that are used in a severe corrosion environment.

[0045] The present invention is not limited to a particular type of plating layer, and so both an electroplated layer and an electroless-plated layer are applicable as the plating layer. Also, in the present invention, there is no particular limitation on the alloy components of the plating layer, and preferred examples of the alloy components include a hot-dip galvanized layer, a hot-dip galvanized layer, and so on. Of course, however, the present invention is not limited to the disclosed components, and so any conventionally known components are applicable.

(Method of producing a high-strength hot-rolled steel sheet)

[0046] Next, a method for producing the hot-rolled steel sheet of the present invention will be described.

[0047] The method of the present invention comprises: heating a steel material (slab) having the above-described composition; subjecting the steel material to hot rolling including rough rolling and finish rolling; and after completion of the finish rolling, cooling and coiling the steel material to gain a hot-rolled steel sheet.

[0048] In the method of the present invention, the steel material is heated at a temperature of 1100 °C or higher and 1350 °C or lower, the finish rolling is operated at a finish rolling temperature of 850 °C or higher, the cooling is initiated within 3 seconds after completion of the finish rolling, the cooling is operated at an average cooling rate of 20 °C/s or

higher, and the coiling is operated at a coiling temperature of 550 °C or higher and 700 °C or lower.

[0049] The present invention is not limited to a particular steelmaking method, and so any known steelmaking method may be adopted, such as using converter, electric furnace, and so on. In addition, secondary refinement may also be operated in a vacuum degassing furnace. Then, while continuous casting is preferably used to cast a slab (steel material) in terms of productivity and quality, any known casting method may also be used to cast a slab, such as ingot casting-blooming or thin slab continuous casting.

Heating temperature of steel material: 1100 °C to 1350 °C

[0050] The steel material (steel slab) thus obtained is subjected to rough rolling and finish rolling. And, in the present invention, the steel material needs to be heated prior to the rough rolling so as to establish substantially uniform austenite phase and dissolve coarse carbides. If the steel material is heated at a temperature below 1100 °C, coarse carbides are not dissolved, and therefore, less carbides are subjected to fine particle distribution at the cooling and coiling step after completion of the hot rolling. This results in a significant deterioration in the strength of the finally obtained hot-rolled steel sheet. Alternatively, if the heating temperature is above 1350 °C, scale defects occur, degrading the surface appearance quality of the steel sheet.

[0051] For this reason, the steel material is to be heated at a temperature of 1100 °C or higher and 1350 °C or lower, preferably 1150 °C or higher and 1320 °C or lower. However, when the steel material is subjected to hot rolling, and if the steel material after casting is at a temperature range of 1100 °C or higher to 1350 °C or lower, or if the carbides in the steel material have been dissolved, then the steel material may be subjected to hot direct rolling without being heated. The present invention is not limited to a particular rough rolling condition.

Finish rolling temperature: 850 °C or higher

[0052] If the finish rolling temperature is below 850 °C, ferrite transformation begins during the finish rolling, which results in microstructures with extended ferrite grains, and furthermore, mixed grain size microstructures with partially grown ferrite grains. This significantly deteriorates the bending workability of the hot-rolled steel sheet. Accordingly, the finish rolling temperature is to be 850 °C or higher, preferably 870 °C or higher. While the upper limit of the finish rolling temperature is not particularly specified herein, the finish rolling temperature is determined by the slab reheating temperature, sheet passage rate and steel sheet thickness. Thus, the upper limit of the finish rolling temperature is substantially 990 °C or lower.

Time to initiate forced cooling after completion of the finish rolling: within 3 seconds

[0053] In the steel sheet under high temperature condition immediately after the finish rolling, carbides are caused by strain-induced precipitation due to large strain energy stored in the austenite phase. Since such carbides are susceptible to coarsening as they precipitate at high temperature, the occurrence of strain-induced precipitation makes it difficult to obtain fine precipitates. Accordingly, the present invention requires forced cooling to be initiated promptly after completion of the hot rolling for the purpose of suppressing strain-induced precipitation, and therefore, cooling is initiated within 3 seconds at the latest, preferably within 2 seconds, after completion of the finish rolling in the present invention.

Average cooling rate: 20 °C/s or higher

[0054] As described above, the longer the steel sheet stayed at high temperature after completion of the finish rolling, the more the carbides prone to coarsening caused by strain-induced precipitation. In addition, while the present invention suppresses austenite to ferrite transformation by means of a predetermined amount of Mn contained in the steel sheet, ferrite transformation would begin at high temperature if the cooling rate is low, in which case carbides are more susceptible to coarsening. Thus, rapid cooling is required after the finish rolling, and the steel sheet needs to be cooled at an average cooling rate of 20 °C/s or higher to avoid the above-described problems. The average cooling rate is preferably 40 °C/s or higher. However, if the cooling rate is excessively increased after completion of the finish rolling, there is a concern that it becomes more difficult to control coiling temperature and to obtain stable strength of the hot-rolled steel sheet. Therefore, the average cooling rate is preferably not higher than 150 °C/s.

Coiling temperature: 550 °C to 700 °C

[0055] If the coiling temperature is below 550 °C, it is not possible to obtain a sufficient amount of carbides, which results in a deterioration in the strength of the steel sheet. On the other hand, if the coiling temperature exceeds 700 °C, the precipitated carbides coarsen and therefore the strength of the steel sheet is reduced. Accordingly, the coiling

temperature is to be 550 °C or higher and 700 °C or lower, preferably 580 °C or higher and 680 °C or lower.

[0056] Additionally, the hot-rolled steel sheet having been subjected to hot rolling and coiling has such properties that will not change whether in a state where scales are attached to the surfaces or in a state where scales have been removed by pickling. In both of these states, the hot-rolled steel sheet exhibits excellent properties as described above. In the present invention, the hot-rolled steel sheet after coiling may also be subjected to plating treatment so that a plating layer is provided on a surface of the hot-rolled steel sheet.

[0057] The hot-rolled steel sheet of the present invention shows a small variability of material properties even when subjected to heating treatment up to 740 °C for a short period of time. Thus, for the purpose of imparting a corrosion resistance property to the hot-rolled steel sheet of the present invention, the steel sheet may be subjected to plating treatment to provide a plating layer on a surface thereof. Since the hot-rolled steel sheet of the present invention can be produced when heated at a temperature of 740 °C or lower during plating treatment, the hot-rolled steel sheet may be subjected to plating treatment without loss of the above-described effects of the present invention. The present invention is not limited to a particular type of plating layer, and so both an electroplated layer and an electroless-plated layer are applicable as the plating layer. Also, in the present invention, there is no particular limitation on the alloy components of the plating layer, and preferred examples of the alloy components include a hot-dip galvanized layer, a hot-dip galvanized annealed layer, and so on. Of course, however, the present invention is not limited to the disclosed components, and so any conventionally known components are applicable.

[0058] Moreover, the present invention is not limited to a particular plating treatment method, and so any conventionally known methods are applicable. Exemplary methods include passing a steel sheet through a continuous galvanizing /galvanizing line with an annealing temperature of 740 °C or lower, followed by immersing the steel sheet in a molten bath and then lifting it from the molten bath. After the plating treatment, the steel sheet may also be subjected to alloying treatment by heating the surfaces of the steel sheet in a furnace, such as a gas furnace.

[0059] As described above, the present invention may provide such a hot-rolled steel sheet, by optimizing the composition and producing conditions thereof, that has microstructures such that an area ratio of ferrite phase is 95 % or more, an average grain size of the ferrite phase is 8 μm or less, and carbides in grains of the ferrite phase have an average particle size of less than 10 nm. In addition, the present invention involves enhancing the strength of the steel sheet, while reducing solute elements and coarse inclusions present in the steel sheet for the purpose of improving the bending workability of the steel sheet. As such, the high-strength hot-rolled steel sheet according to the present invention may have excellent bending workability.

[0060] Moreover, the present invention specifies the producing conditions of the hot-rolled steel sheet, while optimizing the contents of carbide-forming elements (Ti and V, and furthermore, Nb, W, Mo, Hf and Zr) contained in the steel sheet. This allows the above-described carbides having an average particle size of less than 10 nm to be precipitated in the ferrite grains sufficiently, and the tensile strength of the hot-rolled steel sheet to be increased to 980 MPa or more, while maintaining excellent bending workability of the steel sheet. It should be noted that the present invention is preferably applied to a hot-rolled steel sheet having a tensile strength of 1100 MPa or less, more preferably 1052 MPa or less.

EXAMPLES

[0061] Steel materials (steel slabs) of 250 mm thick having the compositions shown in Table 1 were subjected to hot rolling under the hot rolling conditions shown in Table 2 to gain hot-rolled steel sheets having a sheet thickness of 1.4 mm to 3.2 mm, respectively. The cooling rate shown in Table 2 indicates the average cooling rate from the finish rolling temperature to the coiling temperature.

[0062] In addition, some of the resulting hot-rolled steel sheets were passed through a hot-dip galvanizing line with an annealing temperature of 720 °C, and then immersed in a molten bath at 460 °C (plating composition: Zn-0.13 mass% Al), whereby hot-dip galvanized materials (GI materials) were obtained. Further, subsequent to the sheet passage through the hot-dip galvanizing line and the following immersion in the molten bath, some of the hot-dip galvanized materials (GI materials) were subjected to alloying treatment at 520 °C, whereby galvanized annealed materials (GA materials) were obtained. For both GI and GA materials, the coating weight was 45 g/m² to 55 g/m² per surface.

[0063] Besides, it was separately ascertained that austenite to ferrite transformation had not occurred during the cooling step until coiling, except for Steel Sheet Nos. 3 to 5 and 12 to 18. [Table 1]

Table 1

Steel	Chemical Composition (mass%)												Remarks
	C	Si	Mn	P	S	Al	N	Ti	V	Nb	Mo, W, Zr, Hf	Others	
A	0.081	0.01	1.05	0.01	0.0056	0.041	0.0038	0.158	0.10	-	-	-	Conforming Steel
B	0.079	0.02	0.85	0.02	0.0051	0.041	0.0029	0.186	0.12	-	-	-	Conforming Steel
C	0.089	0.01	1.18	0.02	0.0048	0.041	0.0039	0.167	0.12	0.02	-	O: 0.0009, Bi: 0.0001, Ge: 0.0009, Pb: 0.0001, Cd: 0.0001, Pt: 0.0001, Co:0.002, Re: 0.0001	Confirming Steel
D	0.085	0.02	1.02	0.01	0.0053	0.045	0.0026	0.148	0.13	-	Zr: 0.02	Ni: 0.021, Cr: 0.026, Cu: 0.09, As: 0.0008, REM: 0.002, B: 0.0002, Hg: 0.0001, Ag: 0.0001, Rh: 0.0001, Au: 0.0001, Pd: 0.0001	Conforming Steel
E	0.085	0.02	1.05	0.01	0.0057	0.038	0.0048	0.164	0.11	-	-	Zn: 0.0008, Ir: 0.0002, Ru: 0.0002, Ta: 0.001, Sb: 0.001, Mg: 0.002, Ti: 0.0001, Os: 0.0001, Ga: 0.0002	Conforming Steel
F	0.081	0.01	1.07	0.02	0.0051	0.041	0.0039	0.168	0.12	-	Mo:0.02, Hf:0.01	In:0.0001, Ca: 0.002, Po: 0.0002, Sn: 0.01	Conforming Steel
G	0.081	0.01	1.10	0.02	0.0012	0.039	0.0028	0.169	0.11	-	W: 0.02	Se: 0.0001, Te: 0.0001, Be: 0.0002, Sr:0.0002, Tc: 0.0001	Conforming Steel
H	<u>0.052</u>	0.02	1.11	0.01	0.0051	0.041	0.0033	0.158	0.10	-	-	-	Comparative Steel
I	<u>0.112</u>	0.01	1.03	0.01	0.0011	0.040	0.0029	0.166	0.11	-	-	-	Comparative Steel
J	0.082	<u>0.50</u>	1.12	0.02	0.0015	0.046	0.0034	0.169	0.10	-	-	-	Comparative Steel
K	0.085	0.01	<u>0.41</u>	0.02	0.0035	0.041	0.0036	0.166	0.11	-	-	-	Comparative Steel
L	0.081	0.03	<u>1.52</u>	0.01	0.0051	0.040	0.0023	0.161	0.12	-	-	-	Comparative Steel

(continued)

Steel	Chemical Composition (mass%)											Remarks	
	C	Si	Mn	P	S	Al	N	Ti	V	Nb	Mo, W, Zr, Hf		Others
<u>M</u>	0.082	0.01	1.15	0.01	0.0032	0.041	0.0035	<u>0.130</u>	0.10	-	-		Comparative Steel
<u>N</u>	0.085	0.03	1.09	0.01	0.0051	0.040	0.0023	0.161	<u>0.03</u>	-	-	-	Comparative Steel
* Values underlined if out of the scope of the present invention													

[Table 2]

Steel Seet No.	Steel	Hot Rolling Step					Remarks
		Slab Heating Temp. (°C)	Finish Rolling Temp. (°C)	Time to Initiate Cooling *1 (s)	Average Cooping Rate (°C/s)	Coiling Temp. (°C)	
1	A	1250	920	1.2	50	580	Inventive Example
2		1260	910	1.1	55	650	Inventive Example
<u>3</u>		1250	920	1.2	<u>5</u>	620	Comparative Example
4		1250	910	1.0	55	<u>520</u>	Comparative Example
<u>5</u>		1240	910	1.1	60	<u>750</u>	Comparative Example
6	B	1250	920	0.8	55	620	Inventive Example
7	C	1280	940	1.1	60	610	Inventive Example
8	D	1260	930	1.0	60	620	Inventive Example
9	E	1270	960	1.5	65	610	Inventive Example
10	F	1260	930	1.1	60	630	Inventive Example
11	G	1250	920	1.8	80	610	Inventive Example
<u>12</u>	H	1260	920	1.1	60	630	Comparative Example
<u>13</u>	I	1250	910	1.3	60	620	Comparative Example
<u>14</u>	<u>J</u>	1270	930	1.0	65	600	Comparative Example
<u>15</u>	<u>K</u>	1250	910	0.9	55	620	Comparative Example
<u>16</u>	<u>L</u>	1260	900	1.2	60	610	Comparative Example
<u>17</u>	<u>M</u>	1270	930	10	65	630	Comparative Example
<u>18</u>	<u>N</u>	1250	920	1.3	60	590	Comparative Example
* Values undermined if out of the scope of the present invention.							
*1: Time to initiate cooling after completion of the finish rolling (in seconds).							

[0064] Test specimens were taken from the hot-rolled steel sheets thus obtained (hot-rolled steel sheets, GI materials and GA materials) and subjected to the microstructure observation, tensile test and bend test to determine the following:

area ratio of ferrite phase; types and area ratios of phases other than ferrite phase; average grain size of ferrite phase; average particle size of carbides; yield strength; tensile strength; elongation; and limit bending radius. The test method was as follows.

(i) Microstructure observation

[0065] The area ratio of ferrite phase was evaluated in the following procedure. At the central portion of the sheet thickness in a cross-section parallel to the rolling direction, 10 fields of microstructures on which corrosion emerged with 5 % nital were photographed under a scanning optical microscope at 400x magnification. Ferrite phase is such a phase with no corrosion traces or no cementite observed in the grains thereof. In addition, assuming ferrite includes polygonal ferrite, bainitic ferrite, acicular ferrite and granular ferrite, the following parameters were derived: area ratio of ferrite phase; average grain size of ferrite phase; and average particle size of carbides in grains of the ferrite phase.

[0066] The area ratio of ferrite phase was determined by image analysis measuring an area ratio of ferrite phase to the observed field, while separating the ferrite phase from other phases such as bainite or martensite phases. In this case, grain boundaries appeared in linear form were construed as part of ferrite phase. The obtained results on the area ratio of ferrite phase are shown in Table 3.

[0067] The average grain size of ferrite phase was determined by using an intersection method under ASTM E 112-10, where three horizontal lines and three vertical lines were respectively drawn in representative three images, among those taken at 400x magnification as described earlier, to calculate an average among the three images, which was considered as the final average grain size. The obtained results on the average grain size are shown in Table 3.

[0068] The average particle size of carbides in grains of the ferrite phase was determined by using a microfilm method to fabricate samples from the central portion of the sheet thickness of each hot-rolled steel sheet obtained, which samples were then observed under a transmission electronic microscope (at 135,000x magnification) to calculate an average of the precipitate particle size measurements at 100 points or more. In calculating the precipitate particle size, coarse cementite and nitrides having a grain size of 1.0 μm or more were excluded from the calculation. The obtained results on the average particle size of carbides are shown in Table 3.

(ii) Tensile test

[0069] JIS No. 5 tensile test specimens were fabricated from the resulting hot-rolled steel sheets in a direction perpendicular to the rolling direction, and then subjected to tensile tests five times pursuant to JIS Z 2241 (2011) standard to determine the average values of yield strength (YS), tensile strength (TS) and total elongation (EI). Besides, the tensile tests were conducted with crosshead speed of 10 mm/min.

(iii) Bend test (for evaluating bending workability)

[0070] Strip test specimens (100 W mm x 35 L mm) were taken from the resulting hot-rolled steel sheets by shearing work so that their longitudinal direction is vertical to the rolling direction. In this case, a sheared surface and a fractured surface were directed in the same direction at an edge face of each test specimen.

[0071] Each test specimen thus obtained was subjected to bend tests three times using the V-block bend test pursuant to JIS Z 2248, and after the tests, the external appearance of the curved portions of the samples were visually observed, where those samples were considered as having passed the tests if no defects, such as cracks or scars, were observed on the curved portion thereof. The bend tests were carried out by using indenters having different inside radii, where, as shown in the following formula, the minimum inside radius R (mm) of each successful indenter (an indenter with which samples have passed the tests) was divided by the sheet thickness t (mm) of the hot-rolled steel sheet, and the result (R/t) was determined as the limit bending radius:

$$(\text{limit bending radius}) = (\text{minimum inside radius of successful indenter } R) / (\text{sheet thickness of steel sheet } t).$$

A smaller limit bending radius means a better result. Circle represents a good result where the limit bending radius is not more than 2.0, while cross indicates a poor result where the limit bending radius is more than 2.0.

[0072] The obtained results are shown in Table 3.

[0073] [Table 3]

Table 3

Steel Sheet No.	Sheet Thickness of Hot Rolled Steel Sheet (mm)	Planting *2	Microstructure of Hot Rolled Steel Sheet			Mechanical Properties of Hot Rolled Steel Sheet			Bending Workability		Remarks
			AreaRatio of Ferrite Phase (%)	Ferrite Grain Size *3 (μm)	Particle Size of Carbides *4 (nm)	Yield Strength YS (MPa)	Tensile Strength TS (MPa)	Elongation EI (%)	Limit Blending Radius	Evaluation * 5	
1	2.0	-	100	2.8	2	924	995	19	0.5	O	Inventive Example
2	2.3	-	100	3.9	3	913	981	20	0.4	O	Inventive Example
3	2.0	-	100	3.5	10	730	785	22	<0.25	O	Comparative Example
4	2.0	-	89 (balance: bainite)	2.7	2	841	927	15	4.0	X	Comparative Example
5	2.0	-	100	9	11	628	675	23	<0.25	O	Comparative Example
6	1.6	-	100	3.2	2	975	1052	18	0.6	O	Inventive Example
	1.6	GI	100	3.3	2	974	1049	18	0.6	O	Inventive Example
7	1.4	-	100	3.1	2	952	1028	18	0.7	O	Inventive Example
	1.4	GA	100	3.2	3	953	1025	18	<0.4	O	Inventive Example
8	1.8	-	100	3.3	2	942	1013	19	0.6	O	Inventive Example
	1.8	GA	100	3.2	2	935	1010	19	0.6	O	Inventive Example
9	3.2	-	100	4.5	3	961	1030	20	0.9	O	Inventive Example

(continued)

Steel Sheet No.	Sheet Thickness of Hot Rolled Steel Sheet (mm)	Planting *2	Microstructure of Hot Rolled Steel Sheet			Mechanical Properties of Hot Rolled Steel Sheet			Bending Workability		Remarks
			Area Ratio of Ferrite Phase (%)	Ferrite Grain Size *3 (μm)	Particle Size of Carbides *4 (nm)	Yield Strength YS (MPa)	Tensile Strength TS (MPa)	Elongation El (%)	Limit Bending Radius	Evaluation *5	
10	2.3	-	100	3.2	3	952	1014	19	1.3	O	Inventive Example
11	1.8	-	100	4.1	2	961	1029	19	0.6	O	Inventive Example
12	1.6	-	100	4.1	2	834	<u>912</u>	20	0.6	O	Comparative Example
<u>13</u>	1.4	-	<u>92</u> (balance: pearlite)	3.8	3	921	995	18	>5.7	X	Comparative Example
<u>14</u>	1.6	-	100	3.5	2	950	1016	18	>5.0	X	Comparative Example
15	1.2	-	100	6.1	10	851	<u>924</u>	20	1.7	O	Comparative Example
16	1.6	-	100	3.5	2	949	1020	18	>5.0	X	Comparative Example
<u>17</u>	1.8	-	100	3.5	3	888	<u>955</u>	20	0.6	O	Comparative Example
<u>18</u>	2.0	-	100	3.8	3	854	<u>918</u>	21	1.0	O	Comparative Example
* Values underlined if out of the scope of the present invention. *2: "-" indicates a hot rolled steel sheet without plating. "GI" indicates a hot-dip galvanized layer. "GA" indicates a hot rolled steel sheet with a hot-dip galvanized layer. *3: Average crystal grain size of ferrite phase. *4: Average particle size of carbides in ferrite grains. *5: Circle ("O") indicates where the limit bending radius is not more than 2.0, cross (X) indicates where the limit bending radius is more than 2.0.											

[0074] It was found that all of the inventive examples provide hot-rolled steel sheets balancing strength and workability, having a high tensile strength TS of 980 MPa or more and excellent bending workability. In contrast, it was revealed that the comparative examples out of the scope of the present invention fail to demonstrate a predetermined high level of strength, or otherwise fail to offer good bending workability.

INDUSTRIAL APPLICABILITY

[0075] According to the present invention, it is possible to obtain a high-strength hot-rolled steel sheet having a tensile strength of 980 MPa or more and excellent bending workability that is suitably applicable to automobile structural members or the like, ensuring both reduction in the weight of automobile members and formation of automobile members.

Claims

1. A high-strength hot-rolled steel sheet comprising a chemical composition consisting of, in mass%,
C: 0.06 % or more and 0.1 % or less,
Si: 0.09 % or less,
Mn: 0.7 % or more and 1.3 % or less,
P: 0.03 % or less,
S: 0.01 % or less,
Al: 0.1 % or less,
N: 0.01 % or less,
Ti: 0.14 % or more and 0.20 % or less,
V: 0.07 % or more and 0.14 % or less,
optionally Nb: 0.01 % or more and 0.05 % or less, optionally at least one of Mo: 0.05 % or less, W: 0.05 % or less, Zr: 0.05 % or less, and Hf: 0.05 % or less, optionally at least one of O (oxygen), Se, Te, Po, As, Bi, Ge, Pb, Ga, In, Tl, Zn, Cd, Hg, Ag, Au, Pd, Pt, Co, Rh, Ir, Ru, Os, Tc, Re, Ta, Be, Sr, REM, B, Ni, Cr, Sb, Cu, Sn, Mg, and Ca, in a total amount of 0.2 % or less, and the balance being Fe and incidental impurities,
wherein the steel sheet has microstructures such that an area ratio of ferrite phase is 95 % or more, an average grain size of the ferrite phase is 8 μm or less, and carbides in grains of the ferrite phase have an average particle size of less than 10 nm, and
wherein the steel sheet has a tensile strength of 980 MPa or more.
2. The high-strength hot-rolled steel sheet according to claim 1, wherein the chemical composition contains, in mass%, Nb: 0.01 % or more and 0.05 % or less.
3. The high-strength hot-rolled steel sheet according to claim 1 or 2, wherein the chemical composition contains at least one of Mo, W, Zr and Hf, the content of each element being controlled so that Mo: 0.05 % or less, W: 0.05 % or less, Zr: 0.05 % or less, and Hf: 0.05 % or less.
4. The high-strength hot-rolled steel sheet according to any one of claims 1 to 3, wherein the chemical composition contains, in mass%, at least one of O (oxygen), Se, Te, Po, As, Bi, Ge, Pb, Ga, In, Tl, Zn, Cd, Hg, Ag, Au, Pd, Pt, Co, Rh, Ir, Ru, Os, Tc, Re, Ta, Be, Sr, REM, B, Ni, Cr, Sb, Cu, Sn, Mg, and Ca, in a total amount of 0.2 % or less.
5. The high-strength hot-rolled steel sheet according to any one of claims 1 to 4, further comprising a plating layer on a surface of the steel sheet.
6. The high-strength hot-rolled steel sheet according to claim 5, wherein the plating layer is a galvanized layer.
7. The high-strength hot-rolled steel sheet according to claim 5, wherein the plating layer is a galvanized layer.
8. A method of producing a high-strength hot-rolled steel sheet, comprising:
heating a steel material;
subjecting the steel material to hot rolling including rough rolling and finish rolling; and
after completion of the finish rolling, cooling and coiling thus rolled steel material to gain a hot-rolled steel sheet, wherein the steel material has a chemical composition consisting of, in mass%,

C: 0.06 % or more and 0.1 % or less,
 Si: 0.09 % or less,
 Mn: 0.7 % or more and 1.3 % or less,
 P: 0.03 % or less,
 S: 0.01 % or less,
 Al: 0.1 % or less,
 N: 0.01 % or less,
 Ti: 0.14 % or more and 0.20 % or less,
 V: 0.07 % or more and 0.14 % or less,

optionally Nb: 0.01 % or more and 0.05 % or less, optionally at least one of Mo: 0.05 % or less, W: 0.05 % or less, Zr: 0.05 % or less, and Hf: 0.05 % or less, optionally at least one of O (oxygen), Se, Te, Po, As, Bi, Ge, Pb, Ga, In, Tl, Zn, Cd, Hg, Ag, Au, Pd, Pt, Co, Rh, Ir, Ru, Os, Tc, Re, Ta, Be, Sr, REM, B, Ni, Cr, Sb, Cu, Sn, Mg, and Ca, in a total amount of 0.2 % or less, and the balance being Fe and incidental impurities, and wherein the steel material is heated at a temperature of 1100 °C or higher and 1350 °C or lower, the finish rolling is operated at a finish rolling temperature of 850 °C or higher, the cooling is initiated within 3 seconds after completion of the finish rolling, the cooling is operated at an average cooling rate of 20 °C/s or higher, and the coiling is operated at a coiling temperature of 550 °C or higher and 700 °C or lower.

9. The method of producing a high-strength hot-rolled steel sheet according to claim 8, wherein the chemical composition contains, in mass%, Nb: 0.01 % or more and 0.05 % or less.
10. The method of producing a high-strength hot-rolled steel sheet according to claim 8 or 9, wherein the chemical composition contains at least one of Mo, W, Zr and Hf, the content of each element being controlled so that Mo: 0.05 % or less, W: 0.05 % or less, Zr: 0.05 % or less, and Hf: 0.05 % or less.
11. The method of producing a high-strength hot-rolled steel sheet according to any one of claims 8 to 10, wherein the chemical composition contains, in mass%, at least one of O (oxygen), Se, Te, Po, As, Bi, Ge, Pb, Ga, In, Tl, Zn, Cd, Hg, Ag, Au, Pd, Pt, Co, Rh, Ir, Ru, Os, Tc, Re, Ta, Be, Sr, REM, B, Ni, Cr, Sb, Cu, Sn, Mg, and Ca, in a total amount of 0.2 % or less.
12. The method of producing a high-strength hot-rolled steel sheet according to any one of claims 8 to 11, comprising forming a plating layer on a surface of the hot-rolled steel sheet.
13. The method of producing a high-strength hot-rolled steel sheet according to claim 12, wherein the plating layer is a galvanized layer.
14. The method of producing a high-strength hot-rolled steel sheet according to claim 12, wherein the plating layer is a galvanized layer.

Patentansprüche

1. Hochfestes, warmgewalztes Stahlblech mit einer chemischen Zusammensetzung in Masse-% bestehend aus

C: 0,06% oder mehr und 0,1% oder weniger,
 Si: 0,09% oder weniger,
 Mn: 0,7% oder mehr und 1,3% oder weniger
 P: 0,03% oder weniger,
 S: 0,01% oder weniger,
 Al: 0,1% oder weniger,
 N: 0,01% oder weniger,
 Ti: 0,14% oder mehr und 0,20% oder weniger,
 V: 0,07% oder mehr und 0,14% oder weniger,
 optional Nb: 0,01% oder mehr und 0,05% oder weniger, optional zumindest eines aus Mo: 0,05% oder weniger, W: 0,05% oder weniger, Zr: 0,05% oder weniger und Hf: 0,05% oder weniger, optional zumindest eines aus O (Sauerstoff), Se, Te, Po, As, Bi, Ge, Pb, Ga, In, Tl, Zn, Cd, Hg, Ag, Au, Pd, Pt, Co, Rh, Ir, Ru, Os, Tc, Re, Ta,

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Be, Sr, REM, B, Ni, Cr, Sb, Cu, Sn, Mg und Ca in einer Gesamtmenge von 0,2% oder weniger, und als Rest Eisen und nicht zu vermeidende Verunreinigungen, wobei das Stahlblech derart Mikrostrukturen aufweist, dass ein Flächenverhältnis einer Ferritphase 95% oder mehr beträgt, und eine mittlere Korngröße der Ferritphase 8 μm oder weniger beträgt, und Karbide in Körnern der Ferritphase eine mittlere Partikelgröße von weniger als 10 nm aufweisen und, wobei das Stahlblech eine Zugfestigkeit von 980 MPa oder mehr aufweist.

2. Hochfestes, warmgewalztes Stahlblech nach Anspruch 1, wobei

die chemische Zusammensetzung in Masse-% enthält: Nb: 0,01% oder mehr und 0,05% oder weniger.

3. Hochfestes, warmgewalztes Stahlblech nach Anspruch 1 oder 2, wobei

die chemische Zusammensetzung zumindest eines aus Mo, W, Zr und Hf enthält, der Gehalt jedes Elements so gesteuert ist, dass Mo: 0,05% oder weniger, W: 0,05% oder weniger, Zr: 0,05% oder weniger und Hf: 0,05% oder weniger.

4. Hochfestes, warmgewalztes Stahlblech nach einem der Ansprüche 1 bis 3, wobei

die chemische Zusammensetzung in Masse-% zumindest eines aus O (Sauerstoff), Se, Te, Po, As, Bi, Ge, Pb, Ga, In, Tl, Zn, Cd, Hg, Ag, Au, Pd, Pt, Co, Rh, Ir, Ru, Os, Tc, Re, Ta, Be, Sr, REM, B, Ni, Cr, Sb, Cu, Sn, Mg und Ca in einer Gesamtmenge von 0,2% oder weniger enthält.

5. Hochfestes, warmgewalztes Stahlblech nach einem der Ansprüche 1 bis 4, ferner mit einer Überzugsschicht auf einer Oberfläche des Stahlblechs.

6. Hochfestes, warmgewalztes Stahlblech nach Anspruch 5, wobei

die Überzugsschicht eine galvanisierte Schicht ist.

7. Hochfestes, warmgewalztes Stahlblech nach Anspruch 5, wobei

die Überzugsschicht eine galvanisierte und wärmebehandelte Schicht ist.

8. Verfahren zum Herstellen eines hochfesten, warmgewalzten Stahlblechs, mit:

Erwärmen eines Stahlmaterials,
Unterziehen des Stahlmaterials einem Warmwalzen einschließlich Grobwalzen und Fertigwalzen; und
nach Beenden des Fertigwalzens Kühlen und Wickeln des gewalzten Stahlmaterials, um ein warmgewalztes Stahlblech zu erhalten,
wobei das Stahlmaterial eine Zusammensetzung in Masse-% bestehend aus:

C: 0,06% oder mehr und 0,1% oder weniger,

Si: 0,09% oder weniger,

Mn: 0,7% oder mehr und 1,3% oder weniger

P: 0,03% oder weniger,

S: 0,01% oder weniger,

Al: 0,1% oder weniger,

N: 0,01% oder weniger,

Ti: 0,14% oder mehr und 0,20% oder weniger,

V: 0,07% oder mehr und 0,14% oder weniger,

optional Nb: 0,01% oder mehr und 0,05% oder weniger, optional zumindest eines aus Mo: 0,05% oder weniger, W: 0,05% oder weniger, Zr: 0,05% oder weniger und Hf: 0,05% oder weniger, optional zumindest eines aus O (Sauerstoff), Se, Te, Po, As, Bi, Ge, Pb, Ga, In, Tl, Zn, Cd, Hg, Ag, Au, Pd, Pt, Co, Rh, Ir, Ru, Os, Tc, Re, Ta, Be, Sr, REM, B, Ni, Cr, Sb, Cu, Sn, Mg und Ca in einer Gesamtmenge von 0,2% oder weniger, und

als Rest Eisen und nicht zu vermeidende Verunreinigungen aufweist, und

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wobei das Stahlmaterial auf eine Temperatur von 1100°C oder höher und 1350°C oder niedriger erwärmt wird, das Fertigwalzen bei einer Fertigwalztemperatur von 850°C oder höher durchgeführt wird, das Kühlen innerhalb von 3 Sekunden nach Vollendung des Fertigwalzens eingeleitet wird, das Kühlen mit einer durchschnittlichen Kühlrate von 20°C/s oder höher durchgeführt wird und das Wickeln bei einer Wickeltemperatur von 550°C oder höher und 700°C oder niedriger durchgeführt wird.

9. Verfahren zum Herstellen eines hochfesten, warmgewalzten Stahlblechs nach Anspruch 8, wobei

die chemische Zusammensetzung in Masse-% enthält: Nb: 0,01% oder mehr und 0,05 % oder weniger.

10. Verfahren zum Herstellen eines hochfesten, warmgewalzten Stahlblechs nach Anspruch 8 oder 9, wobei

die chemische Zusammensetzung zumindest eines aus Mo, W, Zr und Hf aufweist, die Gehalte jedes Elements so gesteuert sind, dass Mo: 0,05% oder weniger, W: 0,05% oder weniger, Zr: 0,05% oder weniger und Hf: 0,05% oder weniger.

11. Verfahren zum Herstellen eines hochfesten, warmgewalzten Stahlblechs nach einem der Ansprüche 8 bis 10, wobei

die chemische Zusammensetzung in Masse-% zumindest eines aus O (Sauerstoff), Se, Te, Po, As, Bi, Ge, Pb, Ga, In, Tl, Zn, Cd, Hg, Ag, Au, Pd, Pt, Co, Rh, Ir, Ru, Os, Tc, Re, Ta, Be, Sr, REM, B, Ni, Cr, Sb, Cu, Sn, Mg und Ca in einer Gesamtmenge von 0,2% oder weniger enthält.

12. Verfahren zum Herstellen eines hochfesten, warmgewalzten Stahlblechs nach einem der Ansprüche 8 bis 11, mit Ausbilden einer Überzugsschicht auf einer Oberfläche des warmgewalzten Stahlblechs.

13. Verfahren zum Herstellen eines hochfesten, warmgewalzten Stahlblechs nach Anspruch 12, wobei

die Überzugsschicht eine galvanisierte Schicht ist.

14. Verfahren zum Herstellen eines hochfesten, warmgewalzten Stahlblechs nach Anspruch 12, wobei

die Überzugsschicht eine galvanisierte und wärmebehandelte Schicht ist.

Revendications

1. Feuille d'acier laminée à chaud haute résistance comprenant une composition chimique consistant en, en % en masse,

C : 0,06 % ou plus et 0,1 % ou moins,

Si : 0,09 % ou moins,

Mn : 0,7 % ou plus et 1,3 % ou moins,

P : 0,03 % ou moins,

S : 0,01 % ou moins,

Al : 0,1 % ou moins,

N : 0,01 % ou moins,

Ti : 0,14 % ou plus et 0,20 % ou moins,

V : 0,07 % ou plus et 0,14 % ou moins,

optionnellement Nb : 0,01 % ou plus et 0,05 % ou moins, optionnellement au moins l'un de Mo : 0,05 % ou moins,

W : 0,05 % ou moins, Zr : 0,05 % ou moins, et Hf : 0,05 % ou moins, optionnellement au moins l'un de O (oxygène),

Se, Te, Po, As, Bi, Ge, Pb, Ga, In, Tl, Zn, Cd, Hg, Ag, Au, Pd, Pt, Co, Rh, Ir, Ru, Os, Tc, Re, Ta, Be, Sr, REM, B, Ni, Cr, Sb, Cu, Sn, Mg et Ca, en une quantité totale de 0,2 % ou moins, et

le reste étant du Fe et d'inévitables impuretés,

dans laquelle la feuille d'acier présente des microstructures telles qu'un rapport de surface de phase ferrite est de

95 % ou plus, une taille moyenne de grains de la phase ferrite est de 8 µm ou moins, et des carbures dans des

grains de la phase ferrite présentent une taille moyenne de particules inférieure à 10 nm, et

dans laquelle la feuille d'acier présente une résistance à la traction de 980 Mpa ou plus.

2. Feuille d'acier laminée à chaud haute résistance selon la revendication 1, dans laquelle la composition chimique

contient, en % en masse, du Nb : 0,01 % ou plus et 0,05 % ou moins.

3. Feuille d'acier laminée à chaud haute résistance selon la revendication 1 ou 2, dans laquelle la composition chimique contient au moins l'un de Mo, W, Zr et Hf, la teneur en chaque élément étant fixée de sorte que Mo : 0,05 % ou moins, W : 0,05 % ou moins, Zr : 0,05 % ou moins et Hf : 0,05 % ou moins.

4. Feuille d'acier laminée à chaud haute résistance selon l'une quelconque des revendications 1 à 3, dans laquelle la composition chimique contient, en % en masse, au moins l'un de O (oxygène), Se, Te, Po, As, Bi, Ge, Pb, Ga, In, Tl, Zn, Cd, Hg, Ag, Au, Pd, Pt, Co, Rh, Ir, Ru, Os, Tc, Re, Ta, Be, Sr, REM, B, Ni, Cr, Sb, Cu, Sn, Mg et Ca, en une quantité totale de 0,2 % ou moins.

5. Feuille d'acier laminée à chaud haute résistance selon l'une des revendications 1 à 4, comprenant en outre une couche de placage sur une surface de la feuille d'acier.

6. Feuille d'acier laminée à chaud haute résistance selon la revendication 5, dans laquelle la couche de placage est une couche galvanisée.

7. Feuille d'acier laminée à chaud haute résistance selon la revendication 5, dans laquelle la couche de placage est une couche recuite après galvanisation.

8. Procédé de production d'une feuille d'acier laminée à chaud haute résistance comprenant :

un chauffage d'un matériau en acier;

le fait de soumettre le matériau en acier à un laminage à chaud comprenant un laminage brut et un laminage de finition ; et

après l'achèvement du laminage de finition, un refroidissement et un enroulement du matériau en acier ainsi laminé pour obtenir une feuille d'acier laminée à chaud,

dans lequel le matériau en acier présente une composition chimique consistant en, % en masse,

C : 0,06 % ou plus et 0,1 % ou moins,

Si : 0,09 % ou moins,

Mn : 0,7 % ou plus et 1,3 % ou moins,

P : 0,03 % ou moins,

S : 0,01 % ou moins,

Al : 0,1 % ou moins,

N : 0,01 % ou moins,

Ti : 0,14 % ou plus et 0,20 % ou moins,

V : 0,07 % ou plus et 0,14 % ou moins,

optionnellement Nb : 0,01 % ou plus et 0,05 % ou moins, optionnellement au moins l'un de Mo : 0,05 % ou moins, W : 0,05 % ou moins, Zr : 0,05 % ou moins, et Hf : 0,05 % ou moins, optionnellement au moins l'un de O (oxygène), Se, Te, Po, As, Bi, Ge, Pb, Ga, In, Tl, Zn, Cd, Hg, Ag, Au, Pd, Pt, Co, Rh, Ir, Ru, Os, Tc, Re, Ta, Be, Sr, REM, B, Ni, Cr, Sb, Cu, Sn, Mg et Ca, en une quantité totale de 0,2 % ou moins, et

le reste étant du Fe et d'inévitables impuretés,

dans lequel le matériau en acier est chauffé à une température de 1 100°C ou plus et 1350°C ou moins, le laminage de finition est effectué à une température de laminage de finition de 850°C ou plus, le refroidissement est initié dans les 3 secondes après l'achèvement du laminage de finition, le refroidissement est effectué à une vitesse de refroidissement moyenne de 20°C/s ou plus, et l'enroulement est effectué à une température d'enroulement de 550°C ou plus et 700°C ou moins.

9. Procédé de production d'une feuille d'acier laminée à chaud haute résistance selon la revendication 8, dans lequel la composition chimique contient au moins, en % en masse, du Nb : 0,01 % ou plus et 0,05 % ou moins.

10. Procédé de production d'une feuille d'acier laminée à chaud haute résistance selon la revendication 8 ou 9, dans lequel la composition chimique contient au moins l'un de Mo, W, Zr et Hf, la teneur en chaque élément étant fixée de sorte que Mo : 0,05 % ou moins, W : 0,05 % ou moins, Zr : 0,05 % ou moins et Hf : 0,05 % ou moins.

11. Procédé de production d'une feuille d'acier laminée à chaud haute résistance selon l'une quelconque des revendications 8 à 10, dans lequel la composition chimique contient, en % en masse, l'un de O (oxygène), Se, Te, Po, As, Bi, Ge, Pb, Ga, In, Tl, Zn, Cd, Hg, Ag, Au, Pd, Pt, Co, Rh, Ir, Ru, Os, Tc, Re, Ta, Be, Sr, REM, B, Ni, Cr, Sb, Cu,

Sn, Mg et Ca, en une quantité totale de 0,2 % ou moins.

5 **12.** Procédé de production d'une feuille d'acier laminée à chaud haute résistance selon l'une quelconque des revendications 8 à 11, comprenant une formation d'une couche de placage sur une surface de la feuille d'acier laminée à chaud.

13. Procédé de production d'une feuille d'acier laminée à chaud haute résistance selon la revendication 12, dans lequel la couche de placage est une couche galvanisée.

10 **14.** Procédé de production d'une feuille d'acier laminée à chaud haute résistance selon la revendication 12, dans lequel la couche de placage est une couche recuite après galvanisation.

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REFERENCES CITED IN THE DESCRIPTION

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