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(54) HIGH-STRENGTH COLD-ROLLED STEEL PLATE AND METHOD FOR PRODUCING SAME

(57) Provided are a high-strength cold-rolled steel sheet excellent in terms of elongation (EL) and hole expansion ratio (λ) having a low yield ratio (YR) and a method for manufacturing the steel sheet.

The steel sheet has a chemical composition containing, by mass%, C: 0.15% to 0.25%, Si: 1.0% to 2.0%, Mn: 1.8% to 2.5%, P: 0.10% or less, S: 0.010% or less, Al: 0.10% or less, N: 0.010% or less, and the balance being Fe and inevitable impurities, and a multi-phase microstructure including ferrite having an average crystal grain diameter of 5 μm or less in an amount of 30% to 55% in terms of volume fraction, retained austenite having an average crystal grain diameter of 2 μm or less in an amount of 5% to 15% in terms of volume fraction, and tempered martensite having an average crystal grain diameter of 2 μm or less in an amount of 30% to 60% in terms of volume fraction, in which the number of grains of the retained austenite existing in an area of 1000 μm^2 is 10 or more.

EP 3 263 728 A1

Description

Technical Field

[0001] The present invention relates to a high-strength cold-rolled steel sheet having a high elongation (EL), a high hole expansion ratio (λ), and a low yield ratio (YR) and a method for manufacturing the steel sheet, and in particular, to a high-strength cold-rolled steel sheet which can preferably be used for structural parts of, for example, an automobile.

Background Art

[0002] In a situation where an increase in fuel efficiency through the weight reduction of an automobile body is an important issue to be addressed in the automobile field, since there has been progress in reducing the thickness of automobile parts by using a high-strength steel sheet for automobile parts, there is a trend toward using a steel sheet having a tensile strength (TS) of 980 MPa or more. When a high-strength steel sheet which is used for the structural members and reinforcement members of an automobile is subjected to forming in order to obtain parts having complex shapes, the steel sheet is required to be excellent in terms of formability expressed not by a single property such as elongation (EL) or stretch flange formability (hereinafter, also referred to as "hole expansion capability") but by both of the properties. Moreover, in the case where parts are assembled with high dimensional accuracy in order to form a module by performing, for example, arc welding or spot welding without allowing spring back or the like to occur after press forming has been performed, it is important that a steel sheet have a low yield ratio (YR) before work is performed. Here, the term "yield ratio (YR)" refers to the ratio of yield stress (YS) to tensile strength (TS), and YR is expressed as YR = YS/TS.

[0003] Conventionally, examples of known high-strength cold-rolled steel sheet having satisfactory formability and a high strength at the same time include a dual-phase steel sheet (DP steel sheet), which has a multi-phase microstructure composed of ferrite and martensite. However, although a DP steel sheet has a high elongation (EL), a DP steel sheet has a disadvantage in that, since a crack tends to occur due to stress concentration occurring at the interface between ferrite and martensite, there is a deterioration in bendability and hole expansion capability. Therefore, for example, Patent Literature 1 discloses a DP steel sheet in which the crystal grain diameter, volume fraction, and nanoindentation hardness of ferrite are controlled, and it is possible to achieve a high elongation (EL) and excellent bendability with this DP steel sheet.

[0004] In addition, examples of a steel sheet having a high strength and a high elongation (EL) at the same time include TRIP steel sheet. Since this TRIP steel sheet has a steel sheet microstructure including retained austenite, a large elongation (EL) is achieved in the case where the steel sheet is deformed by work performed at a temperature equal to or higher than a temperature at which martensite transformation begins, because retained austenite transforms into martensite through transformation induced by stress. However, in the case of this TRIP steel sheet, there is a disadvantage in that, since retained austenite transforms into martensite when punching work is performed, a crack occurs at the interface with ferrite, which results in a deterioration in hole expansion capability. Therefore, for example, Patent Literature 2 discloses a TRIP steel sheet which includes bainitic ferrite in order to improve hole expansion capability.

Citation List

Patent Literature

[0005]

PTL 1: Japanese Patent No. 4925611
PTL 2: Japanese Patent No. 4716358

Summary of Invention

Technical Problem

[0006] However, since the steel sheet disclosed in Patent Literature 1 has an insufficient elongation (EL) in the case where it has a tensile strength (TS) of 980 MPa or more, it cannot be said that sufficient formability is achieved. In addition, since the steel sheet disclosed in Patent Literature 2 which utilizes retained austenite has a yield ratio (YR) of more than 66% in the case where it has a tensile strength (TS) of 980 MPa or more, spring back tends to occur after work has been performed. As described above, in the case of a high-strength steel sheet having a tensile strength (TS) of 980 MPa or more, it is difficult to achieve a high elongation (EL) and a high hole expansion ratio (λ), which are required

for increasing press formability (hereinafter, also referred to as "formability"), while maintaining a low yield ratio (YR), and it is a fact that a steel sheet which is fully satisfactory in terms of these properties (yield ratio (YR), tensile strength (TS), elongation (EL), and hole expansion ratio (λ)) has not yet been developed.

[0007] Therefore, an object of the present invention is, by solving the problems described above, to provide a high-strength cold-rolled steel sheet excellent in terms of elongation (EL) and hole expansion ratio (λ) having a low yield ratio (YR) and a method for manufacturing the steel sheet.

Solution to Problem

[0008] The present inventors diligently conducted investigations, and, as a result, found that it is possible to achieve a high elongation (EL) and a high hole expansion ratio (λ) while maintaining a low yield ratio (YR) by controlling the crystal grain diameters and volume fractions of steel sheet microstructures, that is, ferrite, retained austenite, and tempered martensite. The present invention has been completed based on the knowledge described above.

[0009] Generally, since movable dislocations are formed in ferrite when martensite transformation occurs in DP steel, DP steel has a low yield ratio (YR). However, since such martensite is hard, voids are formed at its interface, in particular, its interface with soft ferrite when punching work is performed in a hole expansion process, the voids then combine with each other when the punched hole is expanded, and a crack occurs as the combination of the voids progresses. Therefore, there is a decrease in the hole expansion ratio (λ) of DP steel. On the other hand, although there is an increase in hole expansion ratio (λ) by tempering martensite, there is also an increase in yield ratio (YR) at the same time. In addition, although retained austenite significantly increases elongation (EL), since retained austenite, as is the case with hard martensite, causes the formation of voids when punching work is performed in a hole expansion process, there is a decrease in hole expansion ratio (λ). As described above, it is conventionally difficult to improve the balance among elongation (EL), hole expansion ratio (λ), and yield ratio (YR).

[0010] Therefore, the present inventors diligently conducted investigations, and, as a result, found the tempering conditions used for forming tempered martensite in order to increase hole expansion ratio (λ) while achieving low yield ratio (YR). Moreover, it was found that it is possible to inhibit the combination of voids in a hole expansion process by decreasing the average crystal grain diameter of retained austenite and tempered martensite in order to form a steel sheet microstructure in which retained austenite and tempered martensite are finely dispersed, which results in an increase in elongation (EL) and hole expansion ratio (λ). In order to realize such an effect, fine martensite and retained austenite are formed by forming a microstructure composed of bainite and martensite in a first annealing process after cold rolling has been performed, by forming fine austenite through reverse transformation in a second annealing process, by then allowing bainite transformation to occur through cooling, and by then performing rapid cooling. Moreover, it was also found that, by performing tempering on hard martensite in order to form tempered martensite, it is possible to obtain a steel sheet having a high elongation (EL) and a high hole expansion ratio (λ) while achieving a low yield ratio (YR).

[0011] The present invention has been completed based on the knowledge described above, and the subject matter of the present invention is as follows.

[1] A high-strength cold-rolled steel sheet having
a chemical composition containing, by mass%, C: 0.15% to 0.25%, Si: 1.0% to 2.0%, Mn: 1.8% to 2.5%, P: 0.10% or less, S: 0.010% or less, Al: 0.10% or less, N: 0.010% or less, and the balance being Fe and inevitable impurities, and
a multi-phase microstructure including ferrite having an average crystal grain diameter of 5 μm or less in an amount of 30% to 55% in terms of volume fraction, retained austenite having an average crystal grain diameter of 2 μm or less in an amount of 5% to 15% in terms of volume fraction, and tempered martensite having an average crystal grain diameter of 2 μm or less in an amount of 30% to 60% in terms of volume fraction,
in which the number of grains of the retained austenite existing in an area of 1000 μm^2 is 10 or more.

[2] The high-strength cold-rolled steel sheet according to item [1] above, in which the chemical composition further contains, by mass%, one or more selected from V: 0.10% or less, Nb: 0.10% or less, and Ti: 0.10% or less.

[3] The high-strength cold-rolled steel sheet according to item [1] or [2] above, in which the chemical composition further contains, by mass%, B: 0.010% or less.

[4] The high-strength cold-rolled steel sheet according to any one of items [1] to [3] above, in which the chemical composition further contains, by mass%, one or more selected from Cr: 0.50% or less, Mo: 0.50% or less, Cu: 0.50% or less, Ni: 0.50% or less, Ca: 0.0050% or less, and REM: 0.0050% or less.

[5] A method for manufacturing the high-strength cold-rolled steel sheet according to any one of items [1] to [4] above, the method including, after having performed hot rolling and cold rolling on a steel slab, performing continuous annealing on the cold-rolled steel sheet,
the continuous annealing including:

heating the steel sheet to a temperature of 850°C or higher,

holding the steel sheet at a first soaking temperature of 850°C or higher for 30 seconds or more,
then cooling the steel sheet from the first soaking temperature to a temperature of 320°C to 500°C at a first average cooling rate of 3°C/s or more,
holding the steel sheet at a second soaking temperature of 320°C to 500°C for 30 seconds or more,
then cooling the steel sheet to a temperature of 100°C or lower,
heating the steel sheet to a temperature of 750°C or higher at an average heating rate of 3°C/s to 30°C/s,
holding the steel sheet at a third soaking temperature of 750°C or higher for 30 seconds or more,
cooling the steel sheet from the third soaking temperature to a temperature of 350°C to 500°C at a second average cooling rate of 3°C/s or more,
then cooling the steel sheet to a temperature of 100°C or lower at a third average cooling rate of 100°C/s to 1000°C/s,
heating the steel sheet to a temperature of 200°C to 350°C, and
then holding the steel sheet at a fourth soaking temperature of 200°C to 350°C for 120 seconds to 1200 seconds.

[0012] In the present invention, the term "a high-strength cold-rolled steel sheet" refers to a cold-rolled steel sheet having a tensile strength (TS) of 980 MPa or more.

[0013] In addition, in the present invention, the term "an average cooling rate" refers to a value derived by dividing a value derived by subtracting a cooling stop temperature from a cooling start temperature by a cooling time. In addition, the term "an average heating rate" refers to a value derived by dividing a value derived by subtracting a heating start temperature from a heating stop temperature by a heating time.

Advantageous Effects of Invention

[0014] According to the present invention, by controlling the chemical composition and microstructure of a steel sheet, it is possible to stably obtain a high-strength cold-rolled steel sheet having a high elongation (EL) and a high hole expansion ratio (λ), that is, a high-strength cold-rolled steel sheet having a tensile strength (TS) of 980 MPa or more, a low yield ratio (YR) of 66% or less, an elongation (EL) of 19% or more, and a hole expansion ratio (λ) of 30% or more.

Description of Embodiments

[0015] Hereafter, the present invention will be specifically described. The high-strength cold-rolled steel sheet according to the present invention has a chemical composition containing, by mass%, C: 0.15% to 0.25%, Si: 1.0% to 2.0%, Mn: 1.8% to 2.5%, P: 0.10% or less, S: 0.010% or less, Al: 0.10% or less, N: 0.010% or less, and the balance being Fe and inevitable impurities, and a multi-phase microstructure including ferrite having an average crystal grain diameter of 5 μm or less in an amount of 30% to 55% in terms of volume fraction, retained austenite having an average crystal grain diameter of 2 μm or less in an amount of 5% to 15% in terms of volume fraction, and tempered martensite having an average crystal grain diameter of 2 μm or less in an amount of 30% to 60% in terms of volume fraction, in which the number of grains of the retained austenite existing in an area of 1000 μm^2 is 10 or more.

[0016] First, the reasons for the limitations on the chemical element of the high-strength cold-rolled steel sheet according to the present invention will be described. Hereinafter, "%" used when describing a chemical composition shall refer to "mass%".

C: 0.15% to 0.25%

[0017] C is a chemical element which is effective for increasing the strength of a steel sheet and which also contributes to the formation of second phases in the present invention, that is, tempered martensite and retained austenite. In the case where the C content is less than 0.15%, since it is difficult to control the volume fraction of tempered martensite to be 30% or more or the volume fraction of retained austenite to be 5% or more, it is difficult to control tensile strength (TS) to be 980 MPa or more. Therefore, the C content is set to be 0.15% or more, or preferably 0.18% or more. On the other hand, in the case where the C content is more than 0.25%, since there is an increase in the difference in hardness between ferrite and tempered martensite, it is not possible to achieve the desired hole expansion ratio (λ). Therefore, the C content is set to be 0.25% or less, or preferably 0.23% or less.

[0018] Here, in the case of the high-strength cold-rolled steel sheet according to the present invention, the term "a main phase" refers to a ferrite phase, and the term "second phases" described above refers to a tempered martensite phase and a retained austenite phase. In addition, the microstructure of the high-strength cold-rolled steel sheet according to the present invention may include tempered bainite and pearlite.

Si: 1.0% to 2.0%

[0019] Si is a chemical element which is necessary for contributing to the formation of retained austenite by inhibiting the formation of carbides when bainite transformation occurs in the first and second annealing processes. In the case where the Si content is less than 1.0%, it is not possible to form a sufficient amount of retained austenite. Therefore, the Si content is set to be 1.0% or more, or preferably 1.3% or more. On the other hand, in the case where the Si content is more than 2.0%, since the volume fraction of ferrite becomes more than 55%, and since the average crystal grain diameter becomes more than 5 μm, it is not possible to achieve a tensile strength (TS) of 980 MPa or more or a sufficient hole expansion ratio (λ). Therefore, the Si content is set to be 2.0% or less, or preferably 1.8% or less.

Mn: 1.8% to 2.5%

[0020] Mn is a chemical element which contributes to an increase in strength through solid solution strengthening and by facilitating the formation of the second phases and which stabilizes austenite. In the case where the Mn content is less than 1.8%, it is not possible to control the volume fraction of the second phases to be within the desired ranges. Therefore, the Mn content is set to be 1.8% or more. On the other hand, in the case where the Mn content is more than 2.5%, since the volume fraction of tempered martensite becomes more than 60%, and since there is an increase in the hardness of tempered martensite, it is not possible to achieve the desired hole expansion ratio (λ). Therefore, the Mn content is set to be 2.5% or less.

P: 0.10% or less

[0021] Although P contributes to an increase in strength through solid solution strengthening, in the case where the P content is more than 0.10%, since the segregation of P significantly occurs at the grain boundaries, a grain-boundary crack occurs due to the embrittlement of the grain boundaries, which makes it impossible to achieve the desired hole expansion ratio (λ). Therefore, the P content is set to be 0.10% or less, or preferably 0.05% or less.

S: 0.010% or less

[0022] In the case where the S content is more than 0.010%, since large amounts of sulfides such as MnS are formed, voids are formed around the sulfides when punching is performed in a hole expansion test, which makes it impossible to achieve the desired hole expansion ratio (λ). Therefore, the S content is set to be 0.010% or less, or preferably 0.005% or less. On the other hand, although there is no particular limitation on the lower limit of the S content, there is an increase in steel-making costs in order to control the S content to be very small, that is, less than 0.0005%. Therefore, it is preferable that the S content be 0.0005% or more.

Al: 0.10% or less

[0023] Although Al is a chemical element which is necessary for deoxidation, in the case where the Al content is more than 0.10%, this deoxidation effect becomes saturated. Therefore, the Al content is set to be 0.10% or less, or preferably 0.08% or less. On the other hand, in order to realize this deoxidation effect, it is preferable that the Al content be 0.01% or more.

N: 0.010% or less

[0024] Since N decreases the hole expansion ratio (λ) by forming coarse nitrides, it is necessary to decrease the N content. In the case where the N content is more than 0.010%, it is not possible to achieve the desired hole expansion ratio (λ). Therefore, the N content is set to be 0.010% or less, or preferably 0.006% or less.

[0025] The remainder which is different from the constituent chemical elements described above is Fe and inevitable impurities. Examples of the inevitable impurities include Sb, Sn, Zn, and Co, and the acceptable ranges of the contents of these chemical elements are respectively Sb: 0.01% or less, Sn: 0.10% or less, Zn: 0.01% or less, and Co: 0. 10% or less. In addition, even in the case where Ta, Mg, and Zr are added in amounts within the ranges which are common among ordinary steel chemical compositions, there is no decrease in the effects of the present invention.

[0026] In addition, in the present invention, one, two, or more of the following chemical elements may be added in addition to the constituent chemical elements described above.

V: 0.10% or less

[0027] Since V contributes to an increase in strength by forming fine carbonitrides, V may be added as needed. In order to realize such an effect, it is preferable that the V content be 0.01% or more. On the other hand, in the case where the V content is large, there is only a small increase in the effect of increasing strength corresponding to an increase in V content in the case where the V content is more than 0.10%, and there is an increase in alloy costs. Therefore, in the case where V is added, it is preferable that the V content be 0.10% or less.

Nb: 0.10% or less

[0028] Since Nb, like V, contributes to an increase in strength by forming fine carbonitrides, Nb may be added as needed. In order to realize such an effect, it is preferable that the Nb content be 0.005% or more. On the other hand, there is a significant deterioration in elongation (EL) in the case where the Nb content is more than 0.10%. Therefore, it is preferable that the Nb content be 0.10% or less.

Ti: 0.10% or less

[0029] Since Ti, like V, contributes to an increase in strength by forming fine carbonitrides, Ti may be added as needed. In order to realize such an effect, it is preferable that the Ti content be 0.005% or more. On the other hand, in the case where the Ti content is more than 0.10%, there is a significant deterioration in elongation (EL). Therefore, it is preferable that the Ti content be 0.10% or less.

B: 0.010% or less

[0030] Since B is a chemical element which contributes to an increase in strength by increasing hardenability and by facilitating the formation of the second phases and which achieves hardenability without significantly increasing the hardness of tempered martensite, B may be added as needed. In order to realize such effects, it is preferable that the B content be 0.0003% or more. On the other hand, in the case where the B content is more than 0.010%, such effects become saturated. Therefore, it is preferable that the B content be 0.010% or less.

Cr: 0.50% or less

[0031] Since Cr is a chemical element which contributes to an increase in strength by facilitating the formation of the second phases, Cr may be added as needed. In order to realize such an effect, it is preferable that the Cr content be 0.10% or more. On the other hand, in the case where the Cr content is more than 0.50%, an excessive amount of tempered martensite is formed. Therefore, in the case where Cr is added, it is preferable that the Cr content be 0.50% or less.

Mo: 0.50% or less

[0032] Since Mo is a chemical element which contributes to an increase in strength by facilitating the formation of the second phases and by partially forming carbides, Mo may be added as needed. In order to realize such an effect, it is preferable that the Mo content be 0.05% or more. On the other hand, in the case where the Mo content is more than 0.50%, such an effect becomes saturated. Therefore, in the case where Mo is added, it is preferable that the Mo content be 0.50% or less.

Cu: 0.50% or less

[0033] Since Cu is a chemical element which contributes to an increase in strength through solid solution strengthening and by facilitating the formation of the second phases, Cu may be added as needed. In order to realize such an effect, it is preferable that the Cu content be 0.05% or more. On the other hand, in the case where the Cu content is more than 0.50%, such an effect becomes saturated, and surface defects caused by Cu tend to occur. Therefore, in the case where Cu is added, it is preferable that the Cu content be 0.50% or less.

Ni: 0.50% or less

[0034] Since Ni is, like Cu, a chemical element which contributes to an increase in strength through solid solution strengthening and by facilitating the formation of the second phases, Ni may be added as needed. In order to realize

such an effect, it is preferable that the Ni content be 0.05% or more. In addition, in the case where Ni is added in combination with Cu, since Ni is effective for inhibiting surface defects caused by Cu from occurring, adding Ni is effective when Cu is added. On the other hand, in the case where the Ni content is more than 0.50%, such effects become saturated. Therefore, in the case where Ni is added, it is preferable that the Ni content be 0.50% or less.

Ca: 0.0050% or less

[0035] Since Ca contributes to inhibiting a decrease in the hole expansion ratio (λ) due to sulfides by spheroidizing the shape of sulfides, Ca may be added as needed. In order to realize such an effect, it is preferable that the Ca content be 0.0005% or more. On the other hand, in the case where the Ca content is more than 0.0050%, such an effect becomes saturated. Therefore, in the case where Ca is added, it is preferable that the Ca content be 0.0050% or less.

REM: 0.0050% or less

[0036] Since REM, like Ca, contributes to inhibiting a decrease in the hole expansion ratio (λ) due to sulfides by spheroidizing the shape of sulfides, REM may be added as needed. In order to realize such an effect, it is preferable that the REM content be 0.0005% or more. On the other hand, in the case where the REM content is more than 0.0050%, such an effect becomes saturated. Therefore, in the case where REM is added, it is preferable that the REM content be 0.0050% or less.

[0037] Hereafter, the microstructure of the high-strength cold-rolled steel sheet according to the present invention will be described in detail. The high-strength cold-rolled steel sheet according to the present invention includes ferrite, retained austenite, and tempered martensite. In addition, the high-strength cold-rolled steel sheet according to the present invention may include tempered bainite as the remainder of the microstructure. The ferrite has an average crystal grain diameter of 5 μm or less and a volume fraction of 30% to 55%. In addition, the retained austenite has an average crystal grain diameter of 2 μm or less and a volume fraction of 5% to 15%. In addition, the tempered martensite has an average crystal grain diameter of 2 μm or less and a volume fraction of 30% to 60%. In addition, in the case of the high-strength cold-rolled steel sheet according to the present invention, the number of grains of retained austenite having an average crystal grain diameter of 2 μm or less existing in an area of 1000 μm^2 is 10 or more. The term "a volume fraction" here shall refer to a volume fraction with respect to the whole steel sheet, and the same shall apply hereinafter.

[0038] In the case where the volume fraction of ferrite described above is less than 30%, since there is an insufficient amount of soft ferrite, there is a decrease in elongation (EL). Therefore, the volume fraction of ferrite is set to be 30% or more, or preferably 35% or more. On the other hand, in the case where the volume fraction of ferrite is more than 55%, it is difficult to achieve a tensile strength (TS) of 980 MPa or more. Therefore, the volume fraction of ferrite is set to be 55% or less, or preferably 50% or less. In addition, in the case where the average crystal grain diameter of ferrite is more than 5 μm, since voids which have been formed in a punched end surface in a hole expansion process tend to combine with each other when the punched hole is expanded, it is not possible to achieve the desired hole expansion ratio (λ). Moreover, in the case where the average crystal grain diameter of ferrite is more than 5 μm, it is not possible to achieve a yield ratio (YR) of less than the desired value. Therefore, the average crystal grain diameter of ferrite is set to be 5 μm or less.

[0039] In order to achieve a high elongation (EL), it is necessary that the volume fraction of retained austenite be 5% to 15%. In the case where the volume fraction of retained austenite is less than 5%, it is not possible to achieve the desired elongation (EL). Therefore, the volume fraction of retained austenite is set to be 5% or more, or preferably 6% or more. On the other hand, in the case where the volume fraction of retained austenite is more than 15%, it is not possible to achieve the desired hole expansion ratio (λ). Therefore, the volume fraction of retained austenite is set to be 15% or less, or preferably 12% or less. In addition, in order to achieve a high hole expansion ratio (λ), the average crystal grain diameter of retained austenite is set to be 2 μm or less. In the case where the average crystal grain diameter of retained austenite is more than 2 μm, voids tend to combine with each other after the voids have been formed in a hole expansion process. Therefore, the average crystal grain diameter of retained austenite is set to be 2 μm or less.

[0040] In order to achieve a tensile strength of 980 MPa or more while achieving the desired hole expansion ratio (λ) and low yield ratio (YR), the volume fraction of tempered martensite is set to be 30% to 60%. In the case where the volume fraction of tempered martensite is less than 30%, it is not possible to achieve a tensile strength of 980 MPa or more. On the other hand, in the case where the volume fraction of tempered martensite is more than 60%, it is difficult to achieve the desired elongation (EL). In addition, in order to achieve a high hole expansion ratio (λ), the average crystal grain diameter of tempered martensite is set to be 2 μm or less. In the case where the average crystal grain diameter is more than 2 μm, since voids which have been formed at the grain boundaries with ferrite tend to combine with each other, it is not possible to achieve the desired hole expansion ratio (λ). Therefore, the upper limit of the average crystal grain diameter of tempered martensite is set to be 2 μm.

[0041] In addition, in a steel sheet microstructure, tempered bainite may be partially formed in order to form retained

austenite by allowing bainite transformation to occur in an annealing process. Although there is no particular limitation on the volume fraction of this tempered bainite, it is preferable that the volume fraction of tempered bainite be 30% or less in order to achieve a high elongation (EL).

[0042] Moreover, in order to achieve a high elongation (EL), it is necessary that the number of grains of the above-described retained austenite having an average crystal grain diameter of 2 μm or less existing in an area of 1000 μm^2 be 10 or more. In the case where the number of grains of retained austenite existing in an area of 1000 μm^2 is less than 10, it is not possible to achieve the desired elongation (EL). On the other hand, although there is no particular limitation on the upper limit of the number of grains of retained austenite existing in an area of 1000 μm^2, in the case where the number of grains of retained austenite existing in an area of 1000 μm^2 is more than 50, voids which have been formed at the grain boundaries with ferrite tend to combine with each other. Therefore, it is preferable that the number of grains of retained austenite existing in an area of 1000 μm^2 be 50 or less.

[0043] In addition, in the case of the steel sheet according to the present invention, although there is a case where tempered bainite and pearlite are formed in addition to ferrite, retained austenite, and tempered martensite, it is possible to achieve the object of the present invention as long as the above-described conditions regarding the volume fractions and average crystal grain diameters of ferrite, retained austenite, and tempered martensite and the number of grains of retained austenite existing in an area of 1000 μm^2 are satisfied. However, it is preferable that the volume fraction of pearlite be 5% or less. In addition, as described above, it is preferable that the volume fraction of tempered bainite be 30% or less.

[0044] Here, it is possible to observe the multi-phase microstructure of a steel sheet described above by using, for example, a SEM (scanning electron microscope). Specifically, first, a cross section in the thickness direction parallel to the rolling direction of a steel sheet is polished and then etched by using nital (an alcohol solution containing nitric acid). Subsequently, by taking microstructure photographs through the use of a scanning electron microscope at magnifications of 2000 times and 5000 times, by extracting desired regions in the obtained microstructure photograph data through image analysis, it is possible to identify ferrite, retained austenite, tempered martensite, or tempered bainite through the use of image analysis software (Image-Pro ver. 7 produced by Media Cybernetics, Inc.).

[0045] It is possible to determine the above-described desired volume fractions of ferrite, retained austenite, and tempered martensite by determining the area ratios of these phases through the use of a point-counting method (in accordance with ASTM E562-83 (1988)) and by defining the area ratios as the volume fractions. In addition, it is possible to determine the above-described desired average crystal grain diameters of ferrite, retained austenite, and tempered martensite by calculating the circle-equivalent diameters of these phases from a steel sheet microstructure photograph and by calculating the average values of the circle-equivalent diameters. In addition, it is possible to determine the number of grains of retained austenite by counting in the observation of a steel sheet microstructure photograph.

[0046] In addition, it is possible to control the above-described desired volume fractions and average crystal grain diameters of ferrite, retained austenite, and tempered martensite and the number of grains of retained austenite by controlling a steel sheet microstructure when the first annealing is performed and/or when the second annealing is performed.

[0047] Hereafter, the method for manufacturing the high-strength cold-rolled steel sheet according to the present invention will be described.

[0048] The method for manufacturing the high-strength cold-rolled steel sheet according to the present invention includes, after having performed hot rolling and cold rolling on a steel slab having the chemical composition (constituent chemical elements) described above, performing continuous annealing on the cold-rolled steel sheet, in which heating is performed to a temperature of 850°C or higher, in which holding is performed at a first soaking temperature of 850°C or higher for 30 seconds or more, in which cooling is then performed from the first soaking temperature to a second soaking temperature of 320°C to 500°C at a first average cooling rate of 3°C/s or more, in which holding is performed at the second soaking temperature of 320°C to 500°C for 30 seconds or more, in which cooling is then performed to a temperature of 100°C or lower (for example, room temperature), in which heating is thereafter performed to a temperature of 750°C or higher at an average heating rate of 3°C/s to 30°C/s, in which holding is performed at a third soaking temperature of 750°C or higher for 30 seconds or more, in which cooling is then performed from the third soaking temperature to a temperature of 350°C to 500°C at a second average cooling rate of 3°C/s or more, in which cooling is performed to a temperature of 100°C or lower at a third average cooling rate of 100°C/s to 1000°C/s, in which heating is performed to a temperature of 200°C to 350°C, and in which holding is then performed at a fourth soaking temperature of 200°C to 350°C for 120 seconds to 1200 seconds.

[Hot rolling process]

[0049] In the hot rolling process, by performing rough rolling and finish rolling on a steel slab having the chemical composition described above after heating has been performed, a hot-rolled steel sheet is obtained. Although it is preferable that the steel slab used be manufactured by using a continuous casting method in order to prevent the macro

segregation of the constituent chemical elements, the slab may also be manufactured by using an ingot-making method or a thin-slab-casting method. Regarding preferable hot rolling conditions, first, the cast slab may not be reheated or may be reheated to a temperature of 1100°C or higher. In the present invention, in addition to a conventional method, in which, after having manufactured a steel slab, the slab is first cooled to a temperature of 100°C or lower (for example room temperature) and then reheated, an energy-saving process such as a hot direct rolling or a direct rolling, that is, a method in which a slab in the hot state is charged into a heating furnace without the slab having been cooled, a method in which a slab is rolled immediately after heat retention has been performed, or a method in which a slab in the cast state is rolled may be used without causing any problem.

[0050] By controlling a slab heating temperature to be 1100°C or higher, it is possible to decrease rolling load and to improve productivity. On the other hand, by controlling the slab heating temperature to be 1300°C or lower, it is possible to decrease heating costs. Therefore, it is preferable that the slab heating temperature be 1100°C to 1300°C.

[0051] In addition, by controlling a finishing delivery temperature to be 830°C or higher, since it is possible to finish hot rolling within an austenite single phase region, it is possible to inhibit a decrease in elongation (EL) and hole expansion ratio (λ) due to an increase in the inhomogeneity of a microstructure in a steel sheet and the anisotropy of material properties after annealing. On the other hand, by controlling the finishing delivery temperature to be 950°C or lower, it is possible to inhibit deterioration in properties after annealing due to coarsening of a hot-rolled microstructure. Therefore, it is preferable that the finishing delivery temperature be 830°C to 950°C.

[0052] There is no particular limitation on the method used for cooling the hot-rolled steel sheet after hot rolling. Also, there is no particular limitation on a coiling temperature. However, by controlling a coiling temperature to be 700°C or lower, since it is possible to inhibit the formation of coarse pearlite, it is possible to prevent a decrease in elongation (EL) and hole expansion ratio (λ) after annealing has been performed. Therefore, it is preferable that the coiling temperature be 700°C or lower, or more preferably 650°C or lower. On the other hand, although there is no particular limitation on the lower limit of the coiling temperature, by controlling the coiling temperature to be 400°C or higher, since it is possible to inhibit the formation of excessive amounts of hard bainite and martensite, it is possible to decrease cold rolling load. Therefore, it is preferable that the coiling temperature be 400°C or higher.

[Pickling process]

[0053] In the method for manufacturing the high-strength cold-rolled steel sheet according to the present invention, pickling may be performed on the hot-rolled steel sheet after the hot rolling process described above. It is preferable that scale on the surface of the hot-rolled steel sheet be removed by performing pickling. There is no particular limitation on the method used for pickling, and pickling may be performed by using a commonly used method.

[Cold rolling process]

[0054] In the method for manufacturing the high-strength cold-rolled steel sheet according to the present invention, after hot rolling has been performed on the steel slab described above, or after pickling has been performed on the hot-rolled steel sheet, cold rolling, in which rolling is performed in order to obtain a cold-rolled steel sheet having a specified thickness, is performed. There is no particular limitation on the cold rolling process, and cold rolling may be performed by using a commonly used method. In addition, intermediate annealing may be performed before the cold rolling process. By performing intermediate annealing, it is possible to decrease cold rolling load. Although there is no particular limitation on the time or the temperature of the intermediate annealing, in the case where batch annealing is performed on a steel sheet in a coiled state, for example, it is preferable that annealing be performed at a temperature of 450°C to 800°C for 10 minutes to 50 hours.

[Annealing process]

[0055] In the method for manufacturing the high-strength cold-rolled steel sheet according to the present invention, after cold rolling as described above, annealing is performed on the cold-rolled steel sheet. In the annealing process, recrystallization is progressed, and retained austenite and tempered martensite are formed in a steel sheet microstructure in order to increase strength. In addition, in the method for manufacturing the high-strength cold-rolled steel sheet according to the present invention, by performing annealing twice, since it is possible to make fine crystal grains of tempered martensite and retained austenite after annealing, it is possible to achieve a high hole expansion ratio (λ). By allowing untransformed austenite to transform into bainite during a cooling process in the first annealing process, large amounts of fine retained austenite and martensite are retained. However, since the crystal grain diameter of martensite is still large after only the first annealing process has been performed, it is not possible to achieve the desired hole expansion ratio (λ). Therefore, the second annealing is performed in order to further make fine crystal grains of martensite. With this, since martensite and retained austenite, which have been formed in the first annealing process, become the

nucleation sites of austenite which is formed through reverse transformation in the second annealing process, it is possible to perform cooling while maintaining fine phases in the second annealing process. That is, by forming a steel sheet microstructure including bainite, martensite, and retained austenite which are homogenized to some extent in the first annealing process, it is possible to allow more homogeneous fine dispersion to occur in the second annealing process. In order to form tempered martensite in the second annealing process, tempering is performed after cooling is first performed to an excessive degree. With this, it is possible to achieve a high hole expansion ratio (λ) while inhibiting a decrease in elongation (EL).

[0056] Therefore, in the first annealing process, heating is performed to a temperature of 850°C or higher, holding is performed at a first soaking temperature of 850°C or higher for 30 seconds or more, cooling is then performed from the first soaking temperature to a second soaking temperature of 320°C to 500°C at a first average cooling rate of 3°C/s or more, holding is performed at the second soaking temperature of 320°C to 500°C for 30 seconds or more, and cooling is then performed to a temperature of 100°C or lower (for example, room temperature). Thereafter, in the second annealing process, heating is performed to a temperature of 750°C or higher at an average heating rate of 3°C/s to 30°C/s, holding is performed at a third soaking temperature of 750°C or higher for 30 seconds or more, cooling is then performed from the third soaking temperature to a temperature of 350°C to 500°C at a second average cooling rate of 3°C/s or more, cooling is performed to a temperature of 100°C or lower at a third average cooling rate of 100°C/s to 1000°C/s, heating is performed to a temperature of 200°C to 350°C, and holding is then performed at a fourth soaking temperature of 200°C to 350°C for 120 seconds to 1200 seconds.

<First annealing process>

(Heating to first soaking temperature (850°C or higher) and holding for 30 seconds or more)

[0057] In the first annealing process, heating is firstly performed to the first soaking temperature. This first soaking temperature is set to be a temperature in a temperature range in which an austenite single phase is formed. In the case where the first soaking temperature is lower than 850°C, since there is a decrease in the amount of bainite after the first annealing process, there is an increase in the crystal grain diameter of tempered martensite and retained austenite which are formed in the second annealing process, which results in a decrease in hole expansion ratio (λ). Therefore, the lower limit of the first soaking temperature is set to be 850°C, or preferably 870°C or higher. In addition, it is preferable that the first soaking temperature be 1000°C or lower in order to prevent the crystal grain diameter of austenite from increasing. In addition, in order to allow recrystallization to progress and in order to allow the all or part of the grains to transform into austenite, the holding time (soaking time) at the first soaking temperature is set to be 30 seconds or more. Although there is no particular limitation on the upper limit of this holding time, it is preferable that this holding time be 600 seconds or less in order to prevent coarse carbides from being formed in a steel sheet.

(Cooling from first soaking temperature to second soaking temperature (320°C to 500°C) at first average cooling rate (3°C/s or more))

[0058] In the first annealing process, in order to form a steel sheet microstructure including a large amount of bainite, cooling is performed to a second soaking temperature of 320°C to 500°C at a first average cooling rate of 3°C/s or more. In the case where the first average cooling rate is less than 3°C/s, since excessive amounts of ferrite, pearlite and spherical cementite are formed in a steel sheet microstructure, the lower limit of the first average cooling rate is set to be 3°C/s. In addition, in the case where the cooling stop temperature (hereinafter, also referred to as "second soaking temperature") is lower than 320°C, since an excessive amount of massive martensite is formed in the cooling process, it is difficult to form a fine homogeneous steel sheet microstructure in the second annealing process, which makes it impossible to achieve the desired hole expansion ratio (λ). In the case where the cooling stop temperature (second soaking temperature) is higher than 500°C, since there is an excessive increase in the amount of pearlite, it is difficult to form a fine homogeneous steel sheet microstructure in the second annealing process, which makes it impossible to achieve the desired hole expansion ratio (λ). Therefore, the second soaking temperature is set to be 320°C to 500°C, or preferably 350°C to 450°C.

(Holding at second soaking temperature for 30 seconds or more)

[0059] By allowing untransformed austenite to transform into bainite, bainite and retained austenite are formed. In the case where holding time at the second soaking temperature is less than 30 seconds, since there is an increase in the amount of untransformed austenite, there is an increase in the amount of massive martensite in a steel sheet microstructure after the first annealing process, which makes it impossible to make fine crystal grains of a steel sheet microstructure after the second annealing process. Therefore, the holding time at the second soaking temperature is set to

be 30 seconds or more.

(Cooling to a temperature of 100°C or lower)

[0060] After holding has been performed at the second soaking temperature, cooling is performed to a temperature of 100°C or lower (for example, room temperature). With this, it is possible to form a steel sheet microstructure including bainite.

<Second annealing process>

(Heating to third soaking temperature (750°C or higher) at an average heating rate of 3°C/s to 30°C/s)

[0061] In the second annealing process, by forming the nucleation sites of ferrite and austenite which are formed by recrystallization due to reverse transformation, and by controlling the speed of the formation of the nucleation sites of recrystallized ferrite to be larger than that of coarsening of the nucleation sites in order to grow grains, it is possible to make the crystal grains fine after the annealing process. In the case where the third soaking temperature is lower than 750°C, since there is an excessively small amount of austenite formed, it is not possible to achieve the desired volume fractions of martensite and retained austenite formed. Therefore, the third soaking temperature is set to be 750°C or higher. In addition, it is preferable that the third soaking temperature be 900°C or lower in order to remove the influence of the steel sheet microstructure which has been formed in the first annealing process by performing annealing in an austenite single phase region is formed. In addition, in the case where the average heating rate to the third soaking temperature (750°C or higher) is more than 30°C/s, recrystallization is less likely to progress. Therefore, the average heating rate is set to be 30°C/s or less. In addition, in the case where the average heating rate to the third soaking temperature (750°C or higher) is less than 3°C/s, since ferrite grains are coarsened, it is not possible to achieve the specified average crystal grain diameter. Therefore, the average heating rate is set to be 3°C/s or more.

(Holding at third soaking temperature for 30 seconds or more)

[0062] In the second annealing process, holding is performed at a third soaking temperature of 750°C or higher for 30 seconds or more. In the case where the holding time at the third soaking temperature is less than 30 seconds, since insufficient amounts of chemical elements such as Mn are concentrated in austenite, and crystal grains of untransformed austenite are coarsened in the cooling process, it is impossible to achieve the desired hole expansion ratio (λ). Therefore, the holding time at the third soaking temperature is set to be 30 seconds or more.

(Cooling from third soaking temperature to a temperature of 350°C to 500°C at second average cooling rate (3°C/s or more))

[0063] In order to increase elongation (EL) by forming retained austenite, since it is necessary that the concentration of C and Mn in untransformed austenite and bainite transformation be promoted in a cooling process from the third soaking temperature, cooling is performed to a temperature of 350°C to 500°C at a second average cooling rate of 3°C/s or more. In the case where the second average cooling rate is less than 3°C/s, excessive amounts of pearlite and spherical cementite are formed in a steel sheet microstructure. Therefore, the lower limit of the second average cooling rate is set to be 3°C/s. In addition, in the case where cooling at the second average cooling rate is performed to a temperature of lower than 350°C, since an excessive amount of martensite is formed in the cooling process, and the amounts of bainite transformation and retained austenite are decreased due to a decrease in the amount of untransformed austenite, it is impossible to achieve the desired elongation (EL). Therefore, cooling at the second average cooling rate should be performed to a temperature of 350°C or higher. On the other hand, in the case where cooling at the second average cooling rate is performed to a temperature of higher than 500°C, since insufficient amounts of C and Mn are concentrated in untransformed austenite, there is a decrease in the amount of retained austenite formed in the final steel sheet microstructure, which makes it impossible to achieve the desired elongation (EL). Therefore, the cooling at the second average cooling rate should be performed to a temperature of 500°C or lower, or preferably 370°C to 450°C.

(Cooling to a temperature of 100°C or lower at a third average cooling rate of 100°C/s to 1000°C/s)

[0064] Subsequently, in order to form fine martensite and retained austenite, cooling is performed to a temperature of 100°C or lower at a third average cooling rate of 100°C/s to 1000°C/s. In the case where the third average cooling rate is less than 100°C/s, since an excessive amount of bainite is formed, it is not possible to achieve the desired volume fractions. Therefore, the third average cooling rate is set to be 100°C/s or more. On the other hand, in the case where

the third average cooling rate is more than 1000°C/s, a shrinkage cracking may occur in a steel sheet due to cooling. Therefore, the third average cooling rate is set to be 1000°C/s or less. Here, in the case of this cooling, it is preferable that water quenching be performed.

(Tempering)

[0065] After cooling as described above, a tempering treatment is performed. This tempering is performed in order to improve workability by softening martensite. That is, after cooling is performed as described above, in order to temper martensite, after heating has been performed to a temperature of 200°C to 350°C, holding is performed at a tempering temperature of 200°C to 350°C (hereinafter, also referred to as "fourth soaking temperature") for 120 seconds to 1200 seconds. In the case where the tempering temperature (fourth soaking temperature) is lower than 200°C, since the softening of martensite is insufficient, there is a decrease in hole expansion capability. Therefore, the fourth soaking temperature is set to be 200°C or higher. On the other hand, the tempering temperature (fourth soaking temperature) is higher than 350°C, there is an increase in yield ratio (YR). Therefore, the fourth soaking temperature is set to be 350°C or lower, or preferably 300°C or lower. In addition, in the case where the holding time at the fourth soaking temperature is less than 120 seconds, since there is an insufficient improvement in the property of martensite at the fourth soaking temperature, it is not possible to expect the effect of increasing hole expansion ratio (λ). Therefore, the holding time at the fourth soaking temperature is set to be 120 seconds or more. On the other hand, in the case where the holding time at the fourth soaking temperature is more than 1200 seconds, there is a significant decrease in tensile strength due to the softening of martensite progressing excessively, and there is an increase in manufacturing costs due to an increase in reheating time. Therefore, the holding time at the fourth soaking temperature is set to be 1200 seconds or less. Here, after the holding at the above-described temperature, there is no limitation on cooling method or cooling rate.

[0066] In addition, skin pass rolling may be performed after the annealing process. It is preferable that skin pass rolling be performed with an elongation ratio of 0.1% to 2.0%.

[0067] Here, within the range according to the present invention, a galvanized steel sheet may be manufactured by performing a galvanizing treatment in the annealing process, and a galvannealed steel sheet may be manufactured by performing an alloying treatment after a galvanizing treatment has been performed. Moreover, by performing an electroplating treatment on the cold-rolled steel sheet according to the present invention, an electroplated steel sheet may be manufactured.

EXAMPLES

[0068] Hereafter, the examples of the present invention will be described. However, the present invention is not originally limited by the examples described below, and the present invention may be performed by appropriately making alterations within a range in accordance with the intent of the present invention. Working examples performed in such a way are all within the technical scope of the present invention.

[0069] By preparing molten steels having the chemical compositions given in Table 1, by casting the steels in order to manufacture slabs having a thickness of 230 mm, by performing hot rolling under the conditions of a hot rolling heating temperature of 1200°C and a finishing delivery temperature of 900°C, by performing cooling to a temperature of 650°C at a cooling rate of 100°C/s after hot rolling had been performed, and by then performing cooling at a cooling rate of 20°C/s, hot-rolled steel sheets having a thickness of 3.2 mm were obtained and coiled at a coiling temperature of 600°C. Subsequently, by pickling the obtained hot-rolled steel sheets, and by then performing cold rolling, cold-rolled steel sheets (having a thickness of 1.4 mm) were manufactured. Subsequently, in the first annealing process, heating was performed to the first soaking temperatures given in Table 2, annealing was performed at the first soaking temperatures for the first soaking time (first holding time), cooling was the performed to the second soaking temperatures at the first average cooling rates (CR1) given in Table 2, holding was performed for the second soaking time (second holding time), and then cooling was performed to room temperature (25°C). Subsequently, in the second annealing process, heating was performed at the average heating rates given in Table 2, holding was performed at the third soaking temperatures for the third soaking time (third holding time), cooling was then performed to the quenching start temperatures (cooling start temperatures of cooling performed at the third average cooling rates, that is, cooling stop temperatures: Tq) at the second average cooling rates (CR2) given in Table 2, cooling was then performed to room temperature (25°C) at the third average cooling rates (CR3), and then, in the tempering process, heating was performed to the fourth soaking temperatures given in Table 2, holding was performed for the fourth soaking times (fourth holding times given in Table 2), and then cooling was performed to room temperature (25°C).

[Table 1]

Steel Grade	Chemical Composition (mass%)								Note
	C	Si	Mn	P	S	Al	N	Other	
A	0.20	1.45	2.21	0.01	0.002	0.03	0.002	-	Example Steel
B	0.18	1.56	2.19	0.01	0.001	0.03	0.003	Ti:0.02	Example Steel
C	0.21	1.81	2.31	0.01	0.001	0.03	0.003	V:0.02	Example Steel
D	0.22	1.44	1.98	0.01	0.001	0.03	0.002	Nb:0.02	Example Steel
E	0.21	1.64	2.34	0.01	0.002	0.03	0.001	B:0.002	Example Steel
F	0.22	1.31	2.21	0.01	0.001	0.03	0.001	Cr:0.20	Example Steel
G	0.20	1.38	2.14	0.01	0.001	0.03	0.002	Mo:0.20	Example Steel
H	0.19	1.84	2.01	0.01	0.001	0.03	0.002	Cu:0.10	Example Steel
I	0.21	1.65	2.21	0.01	0.001	0.03	0.003	Ni:0.10	Example Steel
J	0.19	1.54	1.89	0.01	0.002	0.03	0.002	Ca:0.0035	Example Steel
K	0.22	1.45	2.22	0.01	0.002	0.03	0.002	REM:0.0028	Example Steel
L	0.11	1.50	2.34	0.01	0.002	0.03	0.002	-	Comparative Steel
M	0.21	0.34	2.48	0.01	0.002	0.02	0.003	-	Comparative Steel
N	0.22	2.12	1.21	0.01	0.002	0.03	0.003	-	Comparative Steel
O	0.19	0.88	3.01	0.02	0.002	0.04	0.002	-	Comparative Steel

• Remainder which is different from the constituent chemical elements described above: Fe and inevitable impurities
• Underlined portion: out of the range according to the present invention

[Table 2]

Sample No.	Steel Grade	Annealing (First) Condition					Annealing (Second) Condition							
		First Soaking Temperature	First Holding Time	CR1 (*1)	Second Soaking Temperature	Second Holding Time	Average Heating Rate	Third Soaking Temperature	Third Holding Time	CR2 (*1)	Tq (*2)	CR3 (*1)	Fourth Soaking Temperature	Fourth Holding Time
		°C	sec	°C/s	°C	sec	°C/s	°C	sec	°C/s	°C	°C/s	°C	sec
1	A	850	300	10	400	600	10	800	600	5	400	880	250	600
2	B	860	600	10	400	300	10	800	600	5	400	900	250	600
3	C	860	600	10	350	600	10	800	600	5	400	900	200	600
4	D	860	300	10	350	600	5	820	500	10	400	800	250	600
5	E	850	300	10	400	300	10	800	300	10	400	840	300	300
6	F	850	200	10	420	600	10	820	120	15	420	880	250	300
7	G	850	120	10	400	300	10	790	300	10	400	800	250	300
8	H	860	300	10	400	300	15	790	300	10	380	800	250	300
9	I	860	300	20	420	300	10	800	300	10	400	890	250	300
10	J	850	120	10	400	300	10	800	300	10	400	880	250	300
11	K	850	100	5	420	600	10	820	600	10	400	900	250	300
12	L	850	300	10	400	600	10	800	300	10	400	880	250	600
13	A	750	120	10	380	600	5	820	300	10	400	880	300	600
14	A	550	3	10	400	600	10	810	300	5	380	900	250	600
15	A	850	300	1	400	600	10	800	300	10	400	900	250	600
16	A	850	300	10	200	600	10	800	300	10	450	900	250	600
17	A	850	300	10	550	300	10	810	300	10	400	880	250	600
18	A	850	300	10	400	10	10	810	300	10	400	880	250	600
19	A	850	300	10	420	300	1	810	300	10	400	890	250	600
20	A	850	300	10	400	600	10	720	300	10	400	900	250	600
21	A	850	300	10	400	600	10	810	300	1	400	800	250	600
22	A	850	300	10	350	600	10	800	300	10	200	880	250	600

(continued)

Sample No.	Steel Grade	Annealing (First) Condition					Annealing (Second) Condition							
		First Soaking Temperature	First Holding Time	CR1 (*1)	Second Soaking Temperature	Second Holding Time	Average Heating Rate	Third Soaking Temperature	Third Holding Time	CR2 (*1)	Tq (*2)	CR3 (*1)	Fourth Soaking Temperature	Fourth Holding Time
		°C	sec	°C/s	°C	sec	°C/s	°C	sec	°C/s	°C	°C/s	°C	sec
23	A	860	300	10	400	300	10	800	300	10	600	890	250	600
24	A	850	300	10	400	300	10	800	300	10	400	880	100	600
25	A	850	300	10	400	300	10	800	600	10	400	900	<u>550</u>	600
26	A	850	300	10	400	300	10	800	300	10	400	800	250	10
27	L	850	300	10	400	300	10	800	300	10	400	900	250	300
28	M	850	300	10	400	300	10	800	300	10	400	880	250	300
29	N	850	300	10	400	300	10	800	300	10	450	880	250	600
30	O	850	300	10	400	300	10	820	300	10	400	900	250	600

Underlined portion: out of the range according to the present invention

*1) CR1, CR2, and CR3 (°C/s): respectively the first average cooling rate, the second average cooling rate, and the third average cooling rate in this order

*2) Tq (°C): cooling stop temperature of cooling performed at the second average cooling rate (cooling start temperature of cooling performed at the third average cooling rate)

[0070] By taking a JIS No. 5 tensile test piece from the manufactured steel sheet so that a direction at a right angle to the rolling direction was the longitudinal direction (tensile direction) of the test piece, and by performing a tensile test (JIS Z 2241 (1998)), yield strength (YS), tensile strength (TS), elongation (EL), and yield ratio (YR) were determined. A steel sheet having a tensile strength (TS) of 980 MPa or more was judged as a high-strength steel sheet, a steel sheet having an elongation (EL) of 19% or more was judged as a steel sheet having a good elongation (EL), and a steel sheet having a yield ratio (YR) of 66% or less was judged as a steel sheet having the desired low yield ratio (YR).

[0071] In addition, regarding hole expansion capability, in accordance with The Japan Iron and Steel Federation Standard (JFS T 1001 (1996)), by punching a hole having a diameter of 10 mmϕ in a sample with a clearance of 12.5%, by setting the sample on a testing machine so that the burr was on the die side, and by forming the sample with a conical punch having a point angle of 60°, hole expansion ratio (λ) was determined. A steel sheet having a λ (%) of 30% or more was judged as a steel sheet having good hole expansion capability.

[0072] Regarding steel sheet microstructure, by using a SEM (scanning electron microscope), a TEM (transmission electron microscope), and an FE-SEM (field-emission-type scanning electron microscope), steel sheet microstructure was observed in order to identify ferrite, retained austenite, tempered martensite, and other kinds of steel microstructures.

[0073] The volume fractions of ferrite and tempered martensite of the steel sheet were determined by polishing a cross section in the thickness direction parallel to the rolling direction of the steel sheet, by then etching the polished cross section through the use of a 3%-nital solution, by observing the etched cross section through the use of a SEM (scanning electron microscope) at magnifications of 2000 times and 5000 times, by determining the area fraction of each of the phases through the use of a point-counting method (in accordance with ASTM E562-83 (1988)), and by defining the area fraction as the volume fraction. Regarding the average crystal grain diameters of ferrite, retained austenite, and tempered martensite, since it was possible to calculate each area of the phases by inputting the steel sheet microstructure photographs, in which the crystal grains of ferrite, retained austenite, and tempered martensite had been identified in advance, into Image-Pro produced by Media Cybernetics, Inc., by calculating circle-equivalent diameters from the calculated areas, the average crystal grain diameter of each of the phases was defined as the average of the calculated circle-equivalent diameters.

[0074] The volume fraction of retained austenite was determined by polishing the steel sheet in order to expose a surface located at 1/4 of the thickness of the steel sheet and by determining the X-ray diffraction intensities of the surface. By determining the integrated intensities of X-ray diffraction of the (200) plane, (211) plane, and (220) plane of the ferrite of iron and the (200) plane, (220) plane, and (311) plane of the austenite of iron through the use of the Kα ray of Mo as a radiation source with an acceleration voltage of 50 keV in X-ray diffractometry (apparatus: RINT-2200 produced by Rigaku Corporation), and by using the calculating formula described in "X-ray Diffraction Handbook" published by Rigaku Corporation (2000), pp. 26 and 62-64, the volume fraction of retained austenite was determined.

[0075] In addition, the number of grains of retained austenite were determined by counting the number in the observation of a steel sheet photograph taken through the use of a SEM.

[0076] The determined steel sheet microstructure, tensile properties, and hole expansion ratio (λ) are given in Table 3.

[Table 3]

Sample No.	Steel Sheet Microstructure								Tensile Property				Hole Expansion Ratio	Note
	Ferrite		Retained Austenite		Tempered Martensite		Remainder	Number of RA Grains in an Area of 1000 μm^2	YS MPa	TS MPa	EL %	YR %	λ %	
	Volume Fraction /%	Average Grain Diameter/μm	Volume Fraction/%	Average Grain Diameter/μm	Volume Fraction/%	Average Grain Diameter/μm	Kind							
1	46	3	7	1	42	1	TB	15	705	1082	22	65	37	Example
2	48	3	6	1	41	1	TB	11	700	1065	21	66	36	Example
3	51	3	5	2	39	1	TB	13	688	1054	19	65	35	Example
4	48	3	7	1	40	2	TB	12	643	990	22	65	36	Example
5	41	4	6	2	48	2	TB	13	675	1025	20	66	35	Example
6	50	3	6	1	35	1	TB	15	661	1030	20	64	36	Example
7	45	3	7	2	41	2	TB	16	664	1016	19	65	37	Example
8	48	4	5	1	43	1	TB	14	664	1011	22	66	38	Example
9	50	3	6	1	39	2	TB	15	661	1003	23	66	36	Example
10	50	3	6	1	40	2	TB	13	656	1041	22	63	40	Example
11	44	3	6	1	42	2	TB	12	684	1044	22	66	35	Example
12	41	3	7	1	46	1	TB	15	674	1032	21	65	37	Example
13	38	4	6	3	49	4	TB	6	668	1033	19	65	28	Comparative Example
14	44	3	5	3	38	5	TB	8	702	1029	19	68	25	Comparative Example
15	40	4	6	4	39	4	TB	6	721	1001	19	72	27	Comparative Example
16	44	4	5	3	41	5	TB	7	709	1021	19	69	22	Comparative Example
17	46	4	6	3	38	3	TB	9	711	1009	19	70	23	Comparative Example

(continued)

Sample No.	Steel Sheet Microstructure								Tensile Property				Hole Expansion Ratio	Note
	Ferrite		Retained Austenite		Tempered Martensite		Remainder	Number of RA Grains in an Area of 1000 μm^2	YS MPa	TS MPa	EL %	YR %	λ %	
	Volume Fraction /%	Average Grain Diameter/μm	Volume Fraction/%	Average Grain Diameter/μm	Volume Fraction/%	Average Grain Diameter/μm	Kind							
18	47	4	5	4	38	3	TB	5	723	1046	20	69	20	Comparative Example
19	48	6	5	2	40	3	TB	10	661	1002	19	66	22	Comparative Example
20	71	5	6	2	17	2	TB	8	578	892	24	65	34	Comparative Example
21	58	6	7	3	25	2	TB,P	11	645	964	23	67	28	Comparative Example
22	48	4	3	1	36	2	TB	4	681	1001	15	68	32	Comparative Example
23	42	3	2	2	50	4	TB	3	691	1022	14	68	33	Comparative Example
24	44	3	2	2	41	2	TB	2	633	1033	19	68	22	Comparative Example
25	43	4	2	2	40	2	TB	3	729	1039	18	70	33	Comparative Example
26	43	3	4	1	40	2	TB	5	655	1030	19	64	19	Comparative Example
27	69	4	3	2	27	2	TB	7	602	889	22	68	29	Comparative Example
28	39	4	4	2	51	2	TB	3	655	989	18	66	30	Comparative Example
29	68	5	5	2	20	2	TB,P	10	595	876	24	68	35	Comparative Example

(continued)

Sample No.	Steel Sheet Microstructure								Tensile Property				Hole Expansion Ratio	Note
	Ferrite		Retained Austenite		Tempered Martensite		Remainder	Number of RA Grains in an Area of 1000 μm^2	YS MPa	TS MPa	EL %	YR %	λ %	
	Volume Fraction /%	Average Grain Diameter/μm	Volume Fraction/%	Average Grain Diameter/μm	Volume Fraction/%	Average Grain Diameter/μm	Kind							
30	35	3	6	3	63	4	TB	11	729	1088	16	67	22	Comparative Example

Under lined portion: out of the range according to the present invention
Microstructure: TB - tempered bainite, P - pearlite, RA - retained austenite

[0077] From the results given in Table 3, it is clarified that all the examples of the present invention had a multi-phase microstructure including ferrite having an average crystal grain diameter of 5 μm or less in an amount of 30% to 55% in terms of volume fraction, retained austenite having an average crystal grain diameter of 2 μm or less in an amount of 5% to 15% in terms of volume fraction, and tempered martensite having an average crystal grain diameter of 2 μm or less in an amount of 30% to 60% in terms of volume fraction, and, as a result, had good formability represented by an elongation (EL) of 19% or more and a hole expansion ratio (λ) of 30% or more while achieving a tensile strength of 980 MPa or more and a yield ratio (YR) of 66% or less.

[0078] On the other hand, in the case of No. 13 where the average crystal grain diameter of retained austenite was more than 2 μm, where the average crystal grain diameter of tempered martensite was more than 2 μm, and where the number of grains of retained austenite existing in an area of 1000 μm^2 was less than 10, the hole expansion ratio (λ) was less than 30%. In the case of Nos. 14 through 18 where the average crystal grain diameter of retained austenite was more than 2 μm, where the average crystal grain diameter of tempered martensite was more than 2 μm, and where the number of grains of retained austenite existing in an area of 1000 μm^2 was less than 10, the yield ratio (YR) was more than 66%, and the hole expansion ratio (λ) was less than 30%.

[0079] In addition, in the case of No. 19 where the average crystal grain diameter of ferrite was more than 5 μm and where the average crystal grain diameter of tempered martensite was more than 2 μm, the hole expansion ratio (λ) was less than 30%. In the case of No. 20 where the volume fraction of ferrite was more than 55%, where the volume fraction of tempered martensite was less than 30%, and where the number of grains of retained austenite existing in an area of 1000 μm^2 was less than 10, the tensile strength (TS) was less than 980 MPa.

[0080] In the case of No. 21 where the volume fraction of ferrite was more than 55%, where the average crystal grain diameter of ferrite was more than 5 μm, where the average crystal grain diameter of retained austenite was more than 2 μm, and where the volume fraction of tempered martensite was less than 30%, the tensile strength (TS) was less than 980 MPa, the yield ratio (YR) was more than 66%, and the hole expansion ratio (λ) was less than 30%. In the case of No. 22 where the volume fraction of retained austenite was less than 5% and where the number of grains of retained austenite existing in an area of 1000 μm^2 was less than 10, the elongation (EL) was less than 19%, and the yield ratio (YR) was more than 66%.

[0081] In the case of No. 23 where the volume fraction of retained austenite was less than 5%, where the average crystal grain diameter of tempered martensite was more than 2 μm, and where the number of grains of retained austenite existing in an area of 1000 μm^2 was less than 10, the elongation (EL) was less than 19%, and the yield ratio (YR) was more than 66%.

[0082] In the case of Nos. 24 and 26 where the volume fraction of retained austenite was less than 5% and where the number of grains of retained austenite existing in an area of 1000 μm^2 was less than 10, the hole expansion ratio (λ) was less than 30%. In the case of No. 25 where the volume fraction of retained austenite was less than 5% and where the number of grains retained austenite existing in an area of 1000 μm^2 was less than 10, the elongation (EL) was less than 19%, and the yield ratio (YR) was more than 66%.

[0083] In the case of No. 27 where the C content was less than 0.15 mass%, where the volume fraction of ferrite was more than 55%, where the volume fraction of retained austenite was less than 5%, where the volume fraction of tempered martensite was less than 30%, and where the number of grains of retained austenite existing in an area of 1000 μm^2 was less than 10, the tensile strength (TS) was less than 980 MPa, the yield ratio (YR) was more than 66%, and the hole expansion ratio (λ) was less than 30%. In the case of No. 28 where the Si content was less than 1.0 mass%, where the volume fraction of retained austenite was less than 5%, and where the number of grains of retained austenite existing in an area of 1000 μm^2 was less than 10, the elongation (EL) was less than 19%.

[0084] In the case of No. 29 where the Mn content was less than 1.8 mass%, where the volume fraction of ferrite was more than 55%, and where the volume fraction of tempered martensite was less than 30%, the tensile strength (TS) was less than 980 MPa, and the yield ratio (YR) was more than 66%. In the case of No. 30 where the Mn content was more than 2.5 mass%, where the average crystal grain diameter of retained austenite was more than 2 μm, where the volume fraction of tempered martensite was more than 60%, and where the average crystal grain diameter of tempered martensite was more than 2 μm, the elongation (EL) was less than 19%, the yield ratio (YR) was more than 66%, and the hole expansion ratio (λ) was less than 30%.

Claims

1. A high-strength cold-rolled steel sheet having a chemical composition containing, by mass%,

   C: 0.15% to 0.25%,
   Si: 1.0% to 2.0%,

Mn: 1.8% to 2.5%,
P: 0.10% or less,
S: 0.010% or less,
Al: 0.10% or less,
N: 0.010% or less, and

the balance being Fe and inevitable impurities, and
a multi-phase microstructure including
ferrite having an average crystal grain diameter of 5 μm or less in an amount of 30% to 55% in terms of volume fraction, retained austenite having an average crystal grain diameter of 2 μm or less in an amount of 5% to 15% in terms of volume fraction, and
tempered martensite having an average crystal grain diameter of 2 μm or less in an amount of 30% to 60% in terms of volume fraction,
wherein the number of grains of the retained austenite existing in an area of 1000 μm^2 is 10 or more.

2. The high-strength cold-rolled steel sheet according to Claim 1, wherein the chemical composition further contains, by mass%, one or more selected from

V: 0.10% or less,
Nb: 0.10% or less, and
Ti: 0.10% or less.

3. The high-strength cold-rolled steel sheet according to Claim 1 or 2, wherein the chemical composition further contains, by mass%, B: 0.010% or less.

4. The high-strength cold-rolled steel sheet according to any one of Claims 1 to 3, wherein the chemical composition further contains, by mass%, one or more selected from Cr: 0.50% or less,

Mo: 0.50% or less,
Cu: 0.50% or less,
Ni: 0.50% or less,
Ca: 0.0050% or less, and
REM: 0.0050% or less.

5. A method for manufacturing the high-strength cold-rolled steel sheet according to any one of Claims 1 to 4,
the method comprising, after having performed hot rolling and cold rolling on a steel slab, performing continuous annealing on the cold-rolled steel sheet,
the continuous annealing including:

heating the steel sheet to a temperature of 850°C or higher,
holding the steel sheet at a first soaking temperature of 850°C or higher for 30 seconds or more,
then cooling the steel sheet from the first soaking temperature to a temperature of 320°C to 500°C at a first average cooling rate of 3°C/s or more,
holding the steel sheet at a second soaking temperature of 320°C to 500°C for 30 seconds or more,
then cooling the steel sheet to a temperature of 100°C or lower,
heating the steel sheet to a temperature of 750°C or higher at an average heating rate of 3°C/s to 30°C/s,
holding the steel sheet at a third soaking temperature of 750°C or higher for 30 seconds or more,
then cooling the steel sheet from the third soaking temperature to a temperature of 350°C to 500°C at a second average cooling rate of 3°C/s or more,
cooling the steel sheet to a temperature of 100°C or lower at a third average cooling rate of 100°C/s to 1000°C/s,
heating the steel sheet to a temperature of 200°C to 350°C, and
then holding the steel sheet at a fourth soaking temperature of 200°C to 350°C for 120 seconds to 1200 seconds.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2015/006347

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C21D9/46*(2006.01)i, *C22C38/06*(2006.01)i, *C22C38/58*(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00-38/60, C21D9/46

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2016
Kokai Jitsuyo Shinan Koho 1971-2016 Toroku Jitsuyo Shinan Koho 1994-2016

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2013-185196 A (JFE Steel Corp.), 19 September 2013 (19.09.2013), & US 2015/0034219 A1 & WO 2013/132796 A1 & EP 2824210 A1 & CA 2866130 A1 & KR 10-2014-0112581 A & CN 104160055 A & MX 2014010648 A & RU 2557035 C1	1-5
A	JP 2012-153957 A (JFE Steel Corp.), 16 August 2012 (16.08.2012), (Family: none)	1-5
A	JP 2015-34327 A (JFE Steel Corp.), 19 February 2015 (19.02.2015), & WO 2015/019558 A1	1-5

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 March 2016 (15.03.16)	29 March 2016 (29.03.16)
Name and mailing address of the ISA/ Japan Patent Office 3-4-3,Kasumigaseki,Chiyoda-ku, Tokyo 100-8915,Japan	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2015/006347

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2015-34326 A (JFE Steel Corp.), 19 February 2015 (19.02.2015), & WO 2015/019557 A1	1-5
A	JP 2004-308002 A (Kobe Steel, Ltd.), 04 November 2004 (04.11.2004), (Family: none)	1-5

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 4925611 B **[0005]**
- JP 4716358 B **[0005]**

Non-patent literature cited in the description

- X-ray Diffraction Handbook. Rigaku Corporation, 2000, 29-62, 64 **[0074]**