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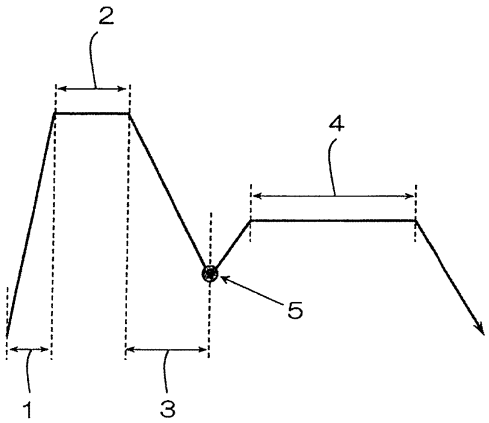
(54) HIGH-STRENGTH COLD-ROLLED STEEL SHEET HAVING EXCELLENT WORKABILITY AND COLLISION CHARACTERISTICS AND HAVING TENSILE STRENGTH OF 980 MPa OR MORE, AND METHOD FOR PRODUCING SAME

(57) Provided are: a high-strength cold-rolled steel sheet having a tensile strength of 980 MPa or more, having good formability as evaluated by ductility and stretch-flangeability, and having excellent crashworthiness; and a method for producing the steel sheet. In this high-strength cold-rolled steel sheet, the metal structure at a position of 1/4 of the sheet thickness satisfies (1) to (4) below. (1) The area ratio of ferrite is 0% or more and 10% or less, with the balance being a hard phase including quenched martensite and retained austenite and including at least one selected from the group consisting of bainitic ferrite, bainite, and tempered martensite. (2) The volume ratio V_γ of retained austenite is 5% or more to 30% or less. (3) The area ratio V_{MA} of an MA structure in which quenched martensite and retained austenite are combined is 3% or more to 25% or less, and the average circle-equivalent diameter of the MA structure is 2.0 μm or less. (4) The ratio V_{MA}/V_γ of the area ratio V_{MA} of the MA structure to the volume ratio V_γ of the retained austenite is 0.50 to 1.50.

FIG. 1



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Description

Technical Field

[0001] The present invention relates to a high-strength cold-rolled steel sheet having a tensile strength of 980 MPa or more and being excellent in formability and crashworthiness and to a method for producing the same. In further detail, the present invention relates to the high-strength cold-rolled steel sheet described above, a high-strength electrogalvanized steel sheet having an electrogalvanized layer formed on a surface of the high-strength cold-rolled steel sheet, a high-strength hot-dip galvanized steel sheet having a hot-dip galvanized layer formed on a surface of the high-strength cold-rolled steel sheet, and a high-strength hot-dip galvannealed steel sheet having a hot-dip galvannealed layer formed on a surface of the high-strength cold-rolled steel sheet, and to a method for producing the same.

Background Art

[0002] In order to achieve fuel cost reduction of automobiles, transport aircrafts and the like, it is desired to reduce the weight of the automobiles, transport aircrafts and the like. In order to achieve weight reduction, it is effective, for example, to reduce the sheet thickness by using a high-strength steel sheet. However, when the steel sheet is made to have a higher strength, the steel sheet comes to have poorer ductility and stretch-flangeability, thereby degrading the formability into a product shape.

[0003] Also, in steel parts for automobiles, a steel sheet whose surface has been subjected to galvanization such as electrogalvanization (which may hereafter be denoted as EG), hot-dip galvanizing (which may hereafter be denoted as GI), or hot-dip galvannealing (which may hereafter be denoted as GA), which may hereafter be comprehensively referred to as galvanized steel sheet, is often used from the viewpoint of corrosion resistance. In these galvanized steel sheets as well, increase in strength and formability is demanded in the same manner as in the above high-strength steel sheet.

[0004] For example, Patent Literature 1 discloses a hot-dip galvannealed steel sheet having a metal structure in which martensite and retained austenite are mixedly present in ferrite and having a tensile strength TS of 490 to 880 MPa by reinforcement of the complex structure thereof, thus having a good press formability.

[0005] Also, Patent Literature 2 discloses a high-strength steel sheet being excellent in stretch-flangeability in which the steel sheet structure is made of 10 to 50% of a ferrite phase and 10 to 50% of a tempered martensite phase in a volume fraction, with the balance being a hard phase, and in which the average crystal grain size in the steel sheet structure is 10 μm or less.

[0006] In the meantime, it is demanded that the steel parts for automobiles are excellent in crashworthiness which is an ability to efficiently absorb an impact generated when the automobiles come into collision. There is known, for example, Patent Literature 3 as a technique for improving the crashworthiness. Patent Literature 3 discloses a high-strength galvanized steel sheet having a maximum tensile strength of 900 MPa or more and being excellent in collision absorption energy in which a dynamic/static ratio as large as that of a steel sheet of 590 MPa class and a maximum tensile strength of 900 MPa or more are compatible with each other, as well as a method for producing the same. This production method is characterized in that, after performing galvanization, cooling is performed, and rolling is performed with use of a roll having a roughness (Ra) of 3.0 or less.

Citation List

Patent Literature

[0007]

Patent Literature 1: Japanese Patent No. 3527092
Patent Literature 2: Japanese Patent No. 5021108
Patent Literature 3: Japanese Patent No. 5487916

Summary of Invention

Problems to be Solved by the Invention

[0008] According to the techniques disclosed in Patent Literatures 1 and 2, the formability of a steel sheet can be improved. However, no consideration is made on the crashworthiness. In contrast, according to the technique disclosed in Patent Literature 3, the crashworthiness of the steel sheet can be improved. However, no consideration is made on the formability as evaluated by ductility and stretch-flangeability.

[0009] The present invention has been made in view of the aforementioned circumstances, and an object thereof is to provide a high-strength cold-rolled steel sheet having a tensile strength of 980 MPa or more, having good formability as evaluated by ductility and stretch-flangeability, and having excellent crashworthiness. Another object of the present invention is to provide a high-strength electrogalvanized steel sheet having an electro galvanized layer on a surface of the high-strength cold-rolled steel sheet, a high-strength hot-dip galvanized steel sheet having a hot-dip galvanized layer on a surface of the high-strength cold-rolled steel sheet, and a high-strength hot-dip galvannealed steel sheet having a hot-dip galvannealed layer on a surface of the high-strength cold-rolled steel sheet. Still another object of the present invention is to provide a method for producing a high-strength cold-rolled steel sheet, a high-strength hot-dip galvanized steel sheet, and a high-strength hot-dip galvannealed steel sheet having the above properties in combination.

Means for Solving the Problems

[0010] A high-strength cold-rolled steel sheet having a tensile strength of 980 MPa or more according to the present invention that has solved the aforementioned problems is a steel sheet containing, in mass%, C: 0.10% or more to 0.5% or less, Si: 1.0% or more to 3% or less, Mn: 1.5% or more to 7% or less, P: more than 0% to 0.1% or less, S: more than 0% to 0.05% or less, Al: 0.005% or more to 1% or less, N: more than 0% to 0.01% or less, and O: more than 0% to 0.01% or less, with a balance being iron and inevitable impurities. Further, the gist lies in that a metal structure at a position of 1/4 of a sheet thickness satisfies (1) to (4) below. The term "MA" is an abbreviation for Martensite-Austenite Constituent.

(1) When the metal structure is observed with a scanning electron microscope, an area ratio of ferrite relative to a whole of the metal structure is 0% or more to 10% or less, with a balance being a hard phase including quenched martensite and retained austenite and including at least one selected from the group consisting of bainitic ferrite, bainite, and tempered martensite.

(2) When the metal structure is measured by X-ray diffractometry, a volume ratio V_γ of retained austenite relative to the whole of the metal structure is 5% or more to 30% or less.

(3) When the metal structure is observed with an optical microscope, an area ratio V_{MA} of an MA structure, in which quenched martensite and retained austenite are combined, relative to the whole of the metal structure is 3% or more to 25% or less, and an average circle-equivalent diameter of the MA structure is 2.0 μm or less.

(4) A ratio V_{MA}/V_γ of the area ratio V_{MA} of the MA structure to the volume ratio V_γ of the retained austenite satisfies a formula (i) below:

$$0.50 \leq V_{MA}/V_\gamma \leq 1.50 \quad \cdots (i).$$

[0011] The steel sheet may further contain, as other elements, in mass%:

(a) at least one selected from the group consisting of Cr: more than 0% to 1% or less and Mo: more than 0% to 1% or less,

(b) at least one selected from the group consisting of Ti: more than 0% to 0.15% or less, Nb: more than 0% to 0.15% or less, and V: more than 0% to 0.15% or less,

(c) at least one selected from the group consisting of Cu: more than 0% to 1% or less and Ni: more than 0% to 1% or less,

(d) B: more than 0% to 0.005% or less,

(e) at least one selected from the group consisting of Ca: more than 0% to 0.01% or less, Mg: more than 0% to 0.01% or less, and REM: more than 0% to 0.01% or less, and the like.

[0012] A high-strength electrogalvanized steel sheet having an electrogalvanized layer on a surface of the high-strength cold-rolled steel sheet, a high-strength hot-dip galvanized steel sheet having a hot-dip galvanized layer on a surface of the high-strength cold-rolled steel sheet, and a high-strength hot-dip galvannealed steel sheet having a hot-dip galvannealed layer on a surface of the high-strength cold-rolled steel sheet are also comprised within the scope of the present invention.

[0013] The high-strength cold-rolled steel sheet having a tensile strength of 980 MPa or more and being excellent in formability and crashworthiness according to the present invention can be produced by subjecting a steel satisfying a component composition described above to hot rolling with a rolling rate at a final stand of finish rolling being 5 to 25% and with a finish rolling end temperature being the Ar_3 point or higher to 900°C or lower, coiling with a coiling temperature being 600°C or lower, and cooling to room temperature; cold rolling; heating, at an average heating rate of 10°C/second

or more, to a temperature region of the Ac_3 point or higher, and soaking by holding in the temperature region for 50 seconds or more; cooling at an average cooling rate of 10°C/second or more, to an arbitrary cooling stop temperature T°C that lies in a temperature range of 100°C or higher and the Ms point or lower; and heating and holding in a temperature region of higher than the cooling stop temperature T°C to 550°C or lower for 50 seconds or more, and thereafter cooling to room temperature.

[0014] A high-strength hot-dip galvanized steel sheet having a tensile strength of 980 MPa or more and being excellent in formability and crashworthiness according to the present invention can be produced by subjecting a steel satisfying a component composition described above to hot rolling with a rolling rate at a final stand of finish rolling being 5 to 25% and with a finish rolling end temperature being the Ar_3 point or higher to 900°C or lower, coiling with a coiling temperature being 600°C or lower, and cooling to room temperature; cold rolling; heating, at an average heating rate of 10°C/second or more, to a temperature region of the Ac_3 point or higher, and soaking by holding in the temperature region for 50 seconds or more; cooling at an average cooling rate of 10°C/second or more, to an arbitrary cooling stop temperature T°C that lies in a temperature range of 100°C or higher and the Ms point or lower; and heating and holding in a temperature region of higher than the cooling stop temperature T°C to 550°C or lower for 50 seconds or more, and after performing hot-dip galvanizing within a holding time, cooling to room temperature.

[0015] A high-strength hot-dip galvannealed steel sheet having a tensile strength of 980 MPa or more and being excellent in formability and crashworthiness according to the present invention can be produced by subjecting a steel satisfying a component composition described above to hot rolling with a rolling rate at a final stand of finish rolling being 5 to 25% and with a finish rolling end temperature being the Ar_3 point or higher to 900°C or lower, coiling with a coiling temperature being 600°C or lower, and cooling to room temperature; cold rolling; heating, at an average heating rate of 10°C/second or more, to a temperature region of the Ac_3 point or higher, and soaking by holding in the temperature region for 50 seconds or more; cooling at an average cooling rate of 10°C/second or more, to an arbitrary cooling stop temperature T°C that lies in a temperature range of 100°C or higher and the Ms point or lower; and heating and holding in a temperature region of higher than the cooling stop temperature T°C to 550°C or lower for 50 seconds or more, and after performing hot-dip galvanizing within a holding time, further performing an alloying treatment and thereafter cooling to room temperature.

Effects of the Invention

[0016] According to the present invention, the component composition and the metal structure are suitably controlled, so that a high-strength cold-rolled steel sheet, a high-strength electrogalvanized steel sheet, a high-strength hot-dip galvanized steel sheet, and a high-strength hot-dip galvannealed steel sheet having a tensile strength of 980 MPa or more and being excellent both in formability as evaluated by ductility and stretch-flangeability and in crashworthiness can be provided. The high-strength cold-rolled steel sheet, the high-strength electrogalvanized steel sheet, the high-strength hot-dip galvanized steel sheet, and the high-strength hot-dip galvannealed steel sheet according to the present invention is particularly excellent in stretch-flangeability among the formability properties. The present invention can also provide a method for producing the high-strength cold-rolled steel sheet, the high-strength electrogalvanized steel sheet, the high-strength hot-dip galvanized steel sheet, and the high-strength hot-dip galvannealed steel sheet described above. The high-strength cold-rolled steel sheet, the high-strength electrogalvanized steel sheet, the high-strength hot-dip galvanized steel sheet, and the high-strength hot-dip galvannealed steel sheet according to the present invention are extremely useful in the fields of industry such as automobiles.

Brief Description of Drawings

[0017] FIG. 1 is a schematic descriptive view showing one example of a heat treatment pattern performed in the Examples.

Description of Embodiments

[0018] The present inventors have repeatedly made eager studies in order to improve all of ductility, stretch-flangeability, and crashworthiness in a high-strength cold-rolled steel sheet having a tensile strength of 980 MPa or more. As a result, the present inventors have found out that, in order to improve the ductility while ensuring the tensile strength by setting a ferrite fraction in the metal structure to be a predetermined amount or less and setting the balance structure to be a hard phase, it is effective to appropriately control a ratio V_{MA}/V_{γ} of an area ratio V_{MA} of an MA structure, in which quenched martensite and retained austenite are combined, to a volume ratio V_{γ} of retained austenite relative to the whole of the metal structure and that, in order to improve the stretch-flangeability, it is effective to set the ferrite fraction in the metal structure to be a predetermined amount or less and to make the MA structure finer and, in order to improve the crashworthiness, it is effective to make the MA structure finer and to appropriately control the above ratio V_{MA}/V_{γ},

thereby completing the present invention.

[0019] First, the metal structure characterizing the present invention will be described.

[0020] The high-strength cold-rolled steel sheet according to the present invention is characterized in that the metal structure at a position of 1/4 of the sheet thickness satisfies (1) to (4) below.

(1) When the metal structure is observed with a scanning electron microscope, the area ratio of ferrite relative to the whole of the metal structure is 0% or more and 10% or less, with the balance being a hard phase including quenched martensite and retained austenite and including at least one selected from the group consisting of bainitic ferrite, bainite, and tempered martensite.

(2) When the metal structure is measured by X-ray diffractometry, the volume ratio V_γ of retained austenite relative to the whole of the metal structure is 5% or more and 30% or less.

(3) When the metal structure is observed with an optical microscope, the area ratio V_{MA} of an MA structure, in which quenched martensite and retained austenite are combined, relative to the whole of the metal structure is 3% or more and 25% or less, and an average circle-equivalent diameter of the MA structure is 2.0 μm or less.

(4) The volume ratio V_γ of the retained austenite and the area ratio V_{MA} of the MA structure satisfy a formula (i) below:

$$0.50 \leq V_{MA}/V_\gamma \leq 1.50 \quad \cdots(i).$$

[0021] The observation of the above metal structure is carried out all at the position of 1/4 of the sheet thickness, as representing the steel sheet.

[0022] Methods of measuring the fractions in the metal structure as defined in the above (1) to (3) may differ from each other, so that a sum of the fractions may exceed 100%. In other words, in the above (1), the metal structure is observed with a scanning electron microscope, so that the measured area ratio is a ratio obtained when the whole of the metal structure is assumed to be 100%. The area ratio measured with use of a scanning electron microscope includes that of quenched martensite and retained austenite as an area ratio of the hard phase. On the other hand, in the above (2), the retained austenite fraction in the metal structure is calculated by X-ray diffractometry, while in the above (3), the area ratio of the MA structure in which quenched martensite and retained austenite are combined is observed with an optical microscope. For this reason, the fraction of retained austenite and quenched martensite is measured in a duplicated manner by a plurality of methods. Accordingly, a sum of the fractions in the metal structure as defined in the above (1) to (3) may exceed 100%. Also, hereafter, the retained austenite may be denoted as retained γ. Further, the structure in which quenched martensite and retained γ are combined may be denoted as MA structure.

(1) In the present invention, the area ratio of ferrite relative to the whole of the metal structure is set to be 0% or more and 10% or less when the metal structure is observed with a scanning electron microscope. The stretch-flangeability can be improved by suppressing the ferrite amount to be 10 area% or less. In other words, since the high-strength cold-rolled steel sheet according to the present invention is mainly made of a hard phase, the strength can be increased. On the other hand, since ferrite is a soft structure, the difference in strength between the ferrite and the hard phase is large. Accordingly, when the ferrite amount increases, the stretch-flangeability decreases. Also, when ferrite is excessively large in amount, the strength of the steel sheet decreases, making it impossible to ensure a tensile strength of 980 MPa or more. Accordingly, the area ratio of ferrite is set to be 10% or less in the present invention. The area ratio of ferrite is preferably 7% or less, more preferably 5% or less. The ferrite amount is preferably as small as possible, and is most preferably 0 area%.

The balance of the above metal structure is a hard phase including quenched martensite and retained γ as an essential structure and including at least one selected from the group consisting of bainitic ferrite, bainite, and tempered martensite. These hard phases constitute a structure that is harder than ferrite, so that, by making the balance structure be a hard phase while suppressing the ferrite amount to be a predetermined value or less, the strength of the steel sheet can be enhanced to be 980 MPa or more. The reason why quenched martensite and retained γ are contained as an essential structure is, as described later, for the purpose of generating a predetermined amount of an MA structure in which quenched martensite and retained γ are combined.

In addition to the hard phase, the above metal structure may contain at least one selected from the group consisting of pearlite and cementite. A sum area ratio of pearlite and cementite is not particularly limited as long as the effect of the present invention is not deteriorated; however, the sum area ratio is preferably, for example, 20% or less. The sum area ratio is more preferably 15% or less, still more preferably 10% or less.

The area ratio of the above metal structure may be calculated by performing observation with a scanning electron microscope after the position of 1/4 of the sheet thickness is corroded with nital, and the observation magnification may be set to be, for example, 1000 times.

(2) In the present invention, when the metal structure is measured by X-ray diffractometry, the volume ratio V_γ of retained γ relative to the whole of the metal structure is set to be 5% or more to 30% or less. The retained γ produces an effect of suppressing concentration of strain by receiving the strain so as to be deformed and transformed into martensite when the steel sheet is processed, thereby promoting hardening of the deformed portion during the processing. For this reason, the strength - elongation balance of the steel sheet is enhanced, and the ductility can be improved. In order that such an effect may be exhibited, it is necessary that the volume ratio of retained γ is set to be 5% or more. The volume ratio of retained γ is preferably 6% or more, more preferably 7% or more. However, when the volume ratio of retained γ increases excessively, the stretch-flangeability becomes deteriorated. Accordingly, the volume ratio of retained γ is set to be 30% or less in the present invention. The volume ratio of retained γ is preferably 25% or less, more preferably 20% or less.

The above volume ratio of retained γ may be determined by measuring the position of 1/4 of the sheet thickness by X-ray diffractometry. The retained γ exists between the laths of bainitic ferrite or by being included in the MA structure. The above effect by the retained γ is exhibited irrespective of the existence form, so that, in the present invention, the volume ratio was determined by calculating a sum of the amounts of all the retained γ measured by X-ray diffractometry irrespective of the existence form.

(3) In the present invention, when the metal structure is observed with an optical microscope, the area ratio V_{MA} of the MA structure relative to the whole of the metal structure is set to be 3% or more to 25% or less. The above MA structure is a structure that enhances the strength - elongation balance of the steel sheet and can improve the ductility. In order that such an effect may be exhibited, it is necessary that the area ratio of the MA structure is set to be 3% or more. The area ratio of the MA structure is preferably 4% or more, more preferably 5% or more. However, when the area ratio of the MA structure increases excessively, the crashworthiness becomes deteriorated. Accordingly, the area ratio of the MA structure is set to be 25% or less in the present invention. The area ratio of the MA structure is preferably 23% or less, more preferably 20% or less.

Also, in the present invention, the average circle-equivalent diameter of the MA structure is set to be 2.0 μm or less. By making the MA structure be finer, the stretch-flangeability and the crashworthiness can be enhanced. In order that such an effect may be exhibited, it is necessary that the average circle-equivalent diameter of the MA structure is set to be 2.0 μm or less. The average circle-equivalent diameter of the MA structure is preferably 1.8 μm or less, more preferably 1.5 μm or less. According as the MA structure becomes finer, the stretch-flangeability and the crashworthiness will be better, so that a lower limit of the average circle-equivalent diameter of the MA structure is not particularly limited; however, from an industrial point of view, the lower limit is about 0.1 μm.

The above MA structure is a structure in which quenched martensite and retained γ are combined. The quenched martensite means a structure in a state in which untransformed austenite is transformed into martensite during the process in which the steel sheet is cooled from the heating temperature down to room temperature. By observation with an optical microscope, the quenched martensite can be distinguished from the tempered martensite that has been tempered by a heating treatment. In other words, when the metal structure is observed with an optical microscope after being subjected to LePera corrosion, the quenched martensite is observed to be white whereas the tempered martensite is observed to be gray.

The quenched martensite and the retained γ are hardly distinguished from each other by observation with an optical microscope, so that the structure in which quenched martensite and retained γ are combined is measured as the MA structure in the present invention.

The area ratio of the above MA structure is a value as measured at the position of 1/4 of the sheet thickness of the steel sheet.

The average circle-equivalent diameter of the MA structure is a value determined by calculating a circle-equivalent diameter based on the area of each MA structure for all the MA structures that are recognized in the field of observation and calculating an average of the obtained circle-equivalent diameters.

(4) In the present invention, it is important that the ratio V_{MA}/V_γ of the area ratio V_{MA} of the MA structure to the volume ratio V_γ of the retained γ satisfies the following formula (i):

$$0.50 \leq V_{MA}/V_\gamma \leq 1.50 \quad \cdots (i).$$

[0023] The ductility and the crashworthiness are rendered compatible with each other when the value of the above ratio V_{MA}/V_γ is controlled to satisfy the above formula (i). In other words, as described above, the retained γ is positively generated in the present invention in order to enhance the strength - elongation balance that constitutes an index of ductility. As a result of this, the MA structure is inevitably formed in the steel sheet. Further, upon further studies on the strength - elongation balance, it has been found out that, when a predetermined amount of retained γ is generated, it is good to control the area ratio V_{MA} of the MA structure so that the value of the above ratio V_{MA}/V_γ may become 0.50 or

more. The value of the above ratio V_{MA}/V_{γ} is preferably 0.55 or more, more preferably 0.60 or more. However, when the value of the above ratio V_{MA}/V_{γ} becomes excessively large, the MA structure is excessively generated. The quenched martensite that exists in the MA structure is a very hard structure, so that, when the MA structure is excessively generated, cracks are liable to be generated at the interface to other structures at the time of collision, and accordingly, the crashworthiness is rather deteriorated. Therefore, in the present invention, the value of the above ratio V_{MA}/V_{γ} is set to be 1.50 or less in order to reduce the area ratio of quenched martensite in the MA structure to ensure the crashworthiness. The value of the above ratio V_{MA}/V_{γ} is preferably 1.40 or less, more preferably 1.30 or less.

[0024] As shown above, the metal structure of the high-strength cold-rolled steel sheet that characterizes the present invention has been described.

[0025] Next, the component composition of the high-strength cold-rolled steel sheet according to the present invention will be described. Hereafter, "%" with regard to the component composition of a steel sheet means "mass%".

[C: 0.10% or more to 0.5% or less]

[0026] C is an element that is necessary for ensuring the tensile strength of 980 MPa or more and for enhancing the stability of retained γ to ensure a predetermined amount of the retained γ. In the present invention, the C amount is set to be 0.10% or more. The C amount is preferably 0.12% or more, more preferably 0.15% or more. However, when the C amount is excessively large, the strength after hot rolling increases, so that cracks may be generated during the cold rolling, or the weldability of a final product may decrease. Accordingly, the C amount is set to be 0.5% or less. The C amount is preferably 0.40% or less, more preferably 0.30% or less, and still more preferably 0.25% or less.

[Si: 1.0% or more to 3% or less]

[0027] Si is an element that acts as a solute-strengthening element and contributes to a higher strength of the steel. Also, Si suppresses generation of carbide and effectively acts for generation of retained γ, so that Si is an element that is necessary for ensuring an excellent strength - elongation balance. In the present invention, the Si amount is set to be 1.0% or more. The Si amount is preferably 1.2% or more, more preferably 1.35% or more, and still more preferably 1.5% or more. However, when the Si amount is excessively large, a considerable scale is formed during the hot rolling to generate scale marks on the surface of the steel sheet, thereby degrading the surface property. Also, the pickling property is degraded as well. Accordingly, the Si amount is set to be 3% or less. The Si amount is preferably 2.8% or less, more preferably 2.6% or less.

[Mn: 1.5% or more to 7% or less]

[0028] Mn is an element that contributes to a higher strength of the steel sheet by enhancing the hardenability and suppressing the generation of ferrite. Further, Mn is an element that is necessary for stabilizing γ to generate retained γ. In the present invention, the Mn amount is set to be 1.5% or more. The Mn amount is preferably 1.6% or more, more preferably 1.7% or more, still more preferably 1.8% or more, and furthermore preferably 2.0% or more. However, when the Mn amount is excessively large, the strength after hot rolling increases, so that cracks may be generated during the cold rolling, or the weldability of the final product may decrease. Also, when Mn is added in an excessively large amount, Mn is segregated to deteriorate the ductility and the stretch-flangeability. Accordingly, the Mn amount is set to be 7% or less. The Mn amount is preferably 5.0% or less, more preferably 4.0% or less, and still more preferably 3.0% or less.

[P: more than 0% to 0.1% or less]

[0029] P is an impurity element that is inevitably contained and, when contained in an excessively large amount, deteriorates the weldability of the final product. Accordingly, the P amount is set to be 0.1% or less in the present invention. The P amount is preferably 0.08% or less, more preferably 0.05% or less. The smaller the P amount is, the better it is. However, it is industrially difficult to set the P amount to be 0%. A lower limit of the P amount is 0.0005% from the industrial point of view.

[S: more than 0% to 0.05% or less]

[0030] As with P, S is an impurity element that is inevitably contained and, when contained in an excessively large amount, deteriorates the weldability of the final product. Also, S forms sulfide-based inclusions in the steel sheet, thereby causing deterioration of the ductility and the stretch-flangeability of the steel sheet. Accordingly, the S amount is set to be 0.05% or less in the present invention. The S amount is preferably 0.01% or less, more preferably 0.005% or less. The smaller the S amount is, the better it is. However, it is industrially difficult to set the S amount to be 0%. A lower

limit of the S amount is 0.0001% from the industrial point of view.

[Al: 0.005% or more to 1% or less]

[0031] Al is an element that acts as a deoxidizer. In order that such an action may be exhibited, the Al amount is set to be 0.005% or more in the present invention. The Al amount is more preferably 0.01% or more. However, when the Al amount is excessively large, the weldability of the final product is considerably deteriorated. Accordingly, the Al amount is set to be 1% or less in the present invention. The Al amount is preferably 0.8% or less, more preferably 0.6% or less.

[N: more than 0% to 0.01% or less]

[0032] N is an impurity element that is inevitably contained and, when N is contained in an excessively large amount, nitride is deposited in a large amount to deteriorate the ductility, stretch-flangeability, and crashworthiness. Accordingly, the N amount is set to be 0.01% or less in the present invention. The N amount is preferably 0.008% or less, more preferably 0.005% or less. Since nitride in a small amount contributes to a higher strength of the steel sheet, the N amount may be 0.001% or more.

[O: more than 0% to 0.01% or less]

[0033] O is an impurity element that is inevitably contained and, when contained in an excessively large amount, deteriorates the ductility and the crashworthiness. Accordingly, the O amount is set to be 0.01% or less in the present invention. The O amount is preferably 0.005% or less, more preferably 0.003% or less. The smaller the O amount is, the better it is. However, it is industrially difficult to set the O amount to be 0%. A lower limit of the O amount is 0.0001% from the industrial point of view.

[0034] The cold-rolled steel sheet according to the present invention satisfies the aforementioned component composition, and the balance is made of iron and inevitable impurities. The inevitable impurities may include the above-mentioned elements such as P, S, N, and O, which may be brought into the steel depending on the circumstances of raw materials, facility materials, production equipment, and the like, and may also include tramp elements such as Pb, Bi, Sb, and Sn.

[0035] The cold-rolled steel sheet of the present invention may further contain, as other elements,

(a) at least one selected from the group consisting of Cr: more than 0% to 1% or less and Mo: more than 0% to 1% or less,
(b) at least one selected from the group consisting of Ti: more than 0% to 0.15% or less, Nb: more than 0% to 0.15% or less, and V: more than 0% to 0.15% or less,
(c) at least one selected from the group consisting of Cu: more than 0% to 1% or less and Ni: more than 0% to 1% or less,
(d) B: more than 0% to 0.005% or less,
(e) at least one selected from the group consisting of Ca: more than 0% to 0.01% or less, Mg: more than 0% to 0.01% or less, and REM: more than 0% to 0.01% or less, and the like.

[0036] These elements of (a) to (e) may be contained either alone or in an arbitrary combination. The reason why such ranges have been set is as follows.

[(a) at least one selected from the group consisting of Cr: more than 0% to 1% or less and Mo: more than 0% to 1% or less]

[0037] Cr and Mo are each an element that acts to improve the strength of the steel sheet by enhancing hardenability. In order that such an action may be effectively exhibited, the amount of each of Cr and Mo is preferably set to be 0.1% or more, more preferably 0.3% or more. However, when these elements are contained in an excessively large amount, the ductility and the stretch-flangeability decrease. Also excessive addition leads to higher costs. Accordingly, when Cr or Mo is contained alone, the amount is preferably 1% or less, more preferably 0.8% or less, still more preferably 0.5% or less. Cr and Mo may be used either alone or in combination. When Cr and Mo are used in combination, it is preferable that each amount is within the above range of the content when used alone, and a sum of the contents of Cr and Mo is 1.5% or less.

[(b) at least one selected from the group consisting of Ti: more than 0% to 0.15% or less, Nb: more than 0% to 0.15% or less, and V: more than 0% to 0.15% or less]

[0038] Ti, Nb, and V are each an element that acts to improve the strength of the steel sheet by forming carbide and nitride in the steel sheet and to make prior γ grains finer. In order that such an action may be effectively exhibited, the amount of each of Ti, Nb, and V is preferably set to be 0.005% or more, more preferably 0.010% or more. However, when these elements are contained in an excessively large amount, carbide is deposited at the grain boundary, so that the stretch-flangeability and the crashworthiness of the steel sheet are deteriorated. Accordingly, in the present invention, the amount of each of Ti, Nb, and V is preferably set to be 0.15% or less, more preferably 0.12% or less, and still more preferably 0.10% or less. These elements may be used either alone or in combination of two or more that are arbitrarily selected.

[(c) at least one selected from the group consisting of Cu: more than 0% to 1% or less and Ni: more than 0% to 1% or less]

[0039] Cu and Ni are each an element that acts effectively for generation and stabilization of retained γ. Also, Cu and Ni act to improve the corrosion resistance of the steel sheet. In order that such an action may be effectively exhibited, the amount of each of Cu and Ni is preferably set to be 0.05% or more, more preferably 0.10% or more. However, when Cu is contained in an excessively large amount, the hot formability is deteriorated. Accordingly, when Cu is added alone, the amount of Cu is preferably set to be 1% or less, more preferably 0.8% or less, and still more preferably 0.5% or less. On the other hand, when Ni is contained in an excessively large amount, a higher cost is invited, so that the amount of Ni is preferably set to be 1% or less, more preferably 0.8% or less, and still more preferably 0.5% or less. Cu and Ni may be used either alone or in combination. When Cu and Ni are used in combination, the above action is more likely to be exhibited, and also, by incorporation of Ni, the deterioration of hot formability caused by addition of Cu is more likely to be suppressed. When Cu and Ni are used in combination, a sum of the amounts of Cu and Ni is preferably set to be 1.5% or less, more preferably 1.0% or less.

[(d) B: more than 0% to 0.005% or less]

[0040] B is an element that improves hardenability and is an element that acts to allow austenite to exist stably down to room temperature. In order that such an action may be effectively exhibited, the amount of B is preferably set to be 0.0005% or more, more preferably 0.0010% or more, and still more preferably 0.0015% or more. However, when B is contained in an excessively large amount, boride may be generated to deteriorate the ductility. Accordingly, the amount of B is preferably set to be 0.005% or less. The amount of B is more preferably 0.004% or less, still more preferably 0.0035% or less.

[(e) at least one selected from the group consisting of Ca: more than 0% to 0.01% or less, Mg: more than 0% to 0.01% or less, and REM: more than 0% to 0.01% or less]

[0041] Ca, Mg, and REM are elements that act to finely disperse the inclusions in the steel sheet. In order that such an action may be effectively exhibited, the amount of each of Ca, Mg, and REM is preferably set to be 0.0005% or more, more preferably 0.0010% or more. However, when these elements are added in an excessively large amount, the castability, hot formability, and the like may be deteriorated. Accordingly, the amount of each of Ca, Mg, and REM is preferably set to be 0.01% or less, more preferably 0.008% or less, and still more preferably 0.007% or less. These elements may be used either alone or in combination of two or more that are arbitrarily selected. In the present invention, REM is an abbreviation for Rare earth metal (rare earth element), and is meant to include lanthanoid elements which are fifteen elements from La to Lu, and Sc and Y.

[0042] As shown above, the high-strength cold-rolled steel sheet according to the present invention is described.

[0043] An electrogalvanized layer, a hot-dip galvanized layer, or a hot-dip galvannealed layer may be formed on a surface of the high-strength cold-rolled steel sheet. In other words, the scope of the present invention includes a high-strength electrogalvanized steel sheet (which may hereafter be referred to as EG steel sheet) having an electrogalvanized layer formed on a surface of the high-strength cold-rolled steel sheet, a high-strength hot-dip galvanized steel sheet (which may hereafter be referred to as GI steel sheet) having a hot-dip galvanized layer formed on a surface of the high-strength cold-rolled steel sheet, and a high-strength hot-dip galvannealed steel sheet (which may hereafter be referred to as GA steel sheet) having a hot-dip galvannealed layer formed on a surface of the high-strength cold-rolled steel sheet.

[0044] Next, a method for producing the high-strength cold-rolled steel sheet according to the present invention is described.

[0045] The high-strength cold-rolled steel can be produced by subjecting a steel satisfying a component composition described above to hot rolling with a rolling rate at a final stand of finish rolling being 5 to 25% and with a finish rolling

end temperature being the Ar_3 point or higher to 900°C or lower, coiling with a coiling temperature being 600°C or lower, and cooling to room temperature; cold rolling; heating, at an average heating rate of 10°C/second or more, to a temperature region of the Ac_3 point or higher, and soaking by holding in the temperature region for 50 seconds or more; cooling at an average cooling rate of 10°C/second or more, to an arbitrary cooling stop temperature T°C that lies in a temperature range of 100°C or higher and the Ms point or lower; and heating and holding in a temperature region of higher than the cooling stop temperature T°C to 550°C or lower for 50 seconds or more, and thereafter cooling to room temperature.

[0046] Hereafter, the steps will be sequentially described.

[Rolling rate at a final stand of finish rolling: 5 to 25%]

[0047] First, a steel satisfying the aforementioned component composition is heated in accordance with a conventional method. A heating temperature is not particularly limited; however, the heating temperature is preferably set to be, for example, 1000 to 1300°C. When the heating temperature is lower than 1000°C, solid solution of carbide is insufficiently formed, and a sufficient strength is hardly obtained. On the other hand, when the heating temperature is higher than 1300°C, the structure of the hot-rolled steel sheet becomes coarse, and also the MA structure of the cold-rolled steel sheet is liable to become coarse. As a result, the crashworthiness tends to decrease.

[0048] After the heating, hot rolling is carried out. In the present invention, it is important that the rolling rate at a final stand of finish rolling is set to be 5 to 25%. When the rolling rate is less than 5%, the austenite grain size after hot rolling becomes coarse, and the average circle-equivalent diameter of the MA structure in the cold-rolled steel sheet after annealing becomes large. As a result, the stretch-flangeability decreases. Accordingly, in the present invention, it is necessary that the rolling rate is set to be 5% or more. The rolling rate is preferably 6% or more, more preferably 7% or more, and still more preferably 8% or more. However, when the rolling rate exceeds 25%, the average circle-equivalent diameter of the MA structure also becomes large, leading to deterioration of the stretch-flangeability and crashworthiness. The mechanism therefor is not clear; however, this seems to be because the structure after hot rolling is made non-homogeneous. In the present invention, it is necessary that the rolling rate is set to be 25% or less. The rolling rate is preferably 23% or less, more preferably 20% or less.

[Finish rolling end temperature: Ar_3 point or higher to 900°C or lower]

[0049] When the finish rolling end temperature is lower than the temperature of the Ar_3 point, the steel sheet structure after hot rolling becomes non-homogeneous, and the stretch-flangeability decreases. On the other hand, when the finish rolling end temperature exceeds 900°C, recrystallization of austenite occurs to make the crystal grains become coarse, and the average circle-equivalent diameter of the MA structure in the cold-rolled steel sheet becomes large. As a result, the stretch-flangeability decreases. Accordingly, in the present invention, it is necessary that the finish rolling end temperature is set to be 900°C or lower. The finish rolling end temperature is preferably 890°C or lower, more preferably 880°C or lower.

[0050] The temperature of the Ar_3 point was calculated on the basis of the following formula (ii). In the formula, brackets [ ] indicate the content of each element (mass%), and calculation may be made by assuming that the content of an element that is not contained in the steel sheet is 0 mass%.

$$Ar_3 \text{ point } (°C) = 910 - 310 \times [C] - 80 \times [Mn] - 20 \times [Cu] - 15 \times [Cr] - 55 \times [Ni] - 80 \times [Mo] \quad \cdots (ii)$$

[Coiling temperature: 600°C or lower]

[0051] When the coiling temperature exceeds 600°C, the crystal grains become coarse, and the average circle-equivalent diameter of the MA structure in the cold-rolled steel sheet becomes large. As a result, the stretch-flangeability decreases. Accordingly, in the present invention, the coiling temperature is set to be 600°C or lower. The coiling temperature is preferably 580°C or lower, more preferably 570°C or lower, and still more preferably 550°C or lower.

[Cold rolling]

[0052] After the hot rolling, the steel sheet may be coiled, cooled to room temperature, pickled by a conventional method in accordance with the needs, and subsequently cold-rolled by a conventional method. The cold rolling rate in the cold rolling may be set to be, for example, 30 to 80%.

[Annealing]

[0053] After the cold rolling, annealing is carried out by heating, at an average heating rate of 10°C/sec or more, to a temperature region of the Ac_3 point or higher, and soaking by holding in the temperature region for 50 seconds or more. When the average heating rate of heating to the above temperature region after the cold rolling is lower than 10°C/sec, the austenite grains grow and become coarse during the heating, so that the average circle-equivalent diameter of the MA structure in the cold-rolled steel sheet becomes large, and the stretch-flangeability decreases. Accordingly, in the present invention, the average heating rate is set to be 10°C/sec or more. The average heating rate is preferably 12°C/sec or more, more preferably 15°C/sec or more. An upper limit of the above average heating rate is not particularly limited; however, the average heating rate is typically about 100°C/sec at the maximum.

[0054] By setting the soaking temperature to be the Ac_3 point or higher, the generation of ferrite can be suppressed. When the soaking temperature is lower than the temperature of the Ac_3 point, ferrite is generated in an excessively large amount, so that the stretch-flangeability cannot be improved. Accordingly, the soaking temperature is set to be the Ac_3 point or higher in the present invention. The soaking temperature is preferably (Ac_3 point + 10°C) or higher, more preferably (Ac_3 point + 20°C) or higher. An upper limit of the soaking temperature is not particularly limited. However, when the soaking temperature is too high, the austenite may be coarsened, so that the soaking temperature is preferably (Ac_3 point + 100°C) or lower, more preferably (Ac_3 point + 50°C) or lower.

[0055] When the soaking time is less than 50 seconds, the processed structure remains in the cold-rolled steel sheet, and the ductility is deteriorated. Accordingly, in the present invention, the soaking time is set to be 50 seconds or more. The soaking time is preferably 60 seconds or more. An upper limit of the soaking time is not particularly limited; however, when the soaking time is too long, concentration of Mn into the austenite phase proceeds, and the Ms point may decrease, leading to increase or coarsening of the MA structure. Accordingly, the soaking time is preferably set to be 3600 seconds or less, more preferably 3000 seconds or less.

[0056] Regarding the soaking holding in the above temperature region, the steel sheet need not be thermostatically held at the same temperature, so that the steel sheet may be heated and cooled in a fluctuating manner within the above temperature region.

[0057] The temperature of the aforementioned Ac_3 point can be calculated on the basis of the following formula (iii) disclosed in "The Physical Metallurgy of Steels" (William C. Leslie, published by Maruzen Co., Ltd. on May 31, 1985, page 273). In the formula, brackets [ ] indicate the content of each element (mass %), and calculation may be made by assuming that the content of an element that is not contained in the steel sheet is 0 mass%.

$$Ac_3\ (°C) = 910 - 203 \times [C]^{1/2} - 15.2 \times [Ni] + 44.7 \times [Si] + 104 \times [V] + 31.5 \times [Mo] + 13.1 \times [W] - (30 \times [Mn] + 11 \times [Cr] + 20 \times [Cu] - 700 \times [P] - 400 \times [Al] - 120 \times [As] - 400 \times [Ti]) \quad \cdots (iii)$$

[Cooling]

[0058] After the above soaking holding, the steel sheet is cooled to an arbitrary cooling stop temperature T°C that lies in a temperature range of 100°C or higher and the Ms point or lower. By cooling down to this temperature range, untransformed austenite can be transformed to martensite and hard bainite phase, and the MA structure also can be made finer. During this period, martensite exists as quenched martensite immediately after the transformation; however, the martensite is tempered while being reheated and held in a later step and remains as tempered martensite. This tempered martensite does not give adverse effects on any of the ductility, stretch-flangeability, and crashworthiness of the steel sheet. However, when the above cooling stop temperature T exceeds the Ms point, martensite is not generated, and the MA structure generated in the reheating holding step at a high temperature becomes coarse, so that the local deformation capability decreases, and the stretch-flangeability cannot be improved. Moreover, because the MA structure is coarsened, the crashworthiness cannot be improved. Accordingly, in the present invention, the cooling stop temperature T is set to be equal to or lower than the temperature of the Ms point. The cooling stop temperature T is preferably (Ms point - 20°C) or lower, more preferably (Ms point - 50°C) or lower. On the other hand, when the cooling stop temperature T is lower than 100°C, retained γ and the MA structure are hardly generated, so that the ductility cannot be improved. Accordingly, in the present invention, a lower limit of the cooling stop temperature T is set to be 100°C or higher. The cooling stop temperature T is preferably 110°C or higher, more preferably 120°C or higher.

[0059] The temperature of the aforementioned Ms point can be calculated on the basis of the following formula (iv). In the formula, brackets [ ] indicate the content of each element (mass%), and calculation may be made by assuming that the content of an element that is not contained in the steel sheet is 0 mass%.

$$\text{Ms point (°C)} = 561 - 474 \times [C] - 33 \times [Mn] - 17 \times [Ni] - 17 \times [Cr] - 21 \times [Mo] \quad \cdots \text{(iv)}$$

[0060] After performing the above soaking and holding, it is important that an average cooling rate down to the cooling stop temperature T that lies in the above temperature range is set to be 10°C/sec or more. Excessive generation of ferrite can be suppressed by appropriately controlling the cooling rate down to the cooling stop temperature T after soaking and holding. In other words, when the average cooling rate is lower than 10°C/sec, ferrite is excessively generated during the cooling, and the stretch-flangeability decreases. Accordingly, in the present invention, the average cooling rate is set to be 10°C/sec or more. The average cooling rate is preferably 15°C/sec or more, more preferably 20°C/sec or more. An upper limit of the above average cooling rate is not particularly limited, and the steel sheet may be cooled by cooling with water or cooling with oil.

[Reheating step]

[0061] After the steel sheet is cooled down to an arbitrary cooling stop temperature T°C that lies in the temperature range of 100°C or higher and the Ms point or lower, it is important that the steel sheet is reheated to a temperature region of higher than the cooling stop temperature T°C to 550°C or lower, and the steel sheet is held in this temperature region for 50 seconds or more. By reheating to the temperature region of higher than the cooling stop temperature T°C to 550°C or lower, the hard phase such as martensite can be tempered, and untransformed austenite can be transformed to bainitic ferrite or bainite. When the reheating is not carried out, the balance between the amounts of generation of retained γ and the MA structure becomes degraded, and the ratio V_{MA}/V_{γ} of the area ratio V_{MA} of the MA structure to the volume ratio V_{γ} of the retained γ cannot be controlled to be within an appropriate range. As a result, the crashworthiness cannot be improved. Further, the hard phase cannot be tempered, and dislocation at a high density is generated. Accordingly, in the present invention, the steel sheet is reheated to a temperature exceeding the cooling stop temperature T after the steel sheet is cooled to the cooling stop temperature T. The reheating temperature is preferably (T + 20°C) or higher, more preferably (T + 30°C) or higher, and still more preferably (T + 50°C) or higher. However, when the reheating temperature exceeds 550°C, retained γ and the MA structure are generated only in a slight amount, so that the tensile strength decreases. Accordingly, in the present invention, the reheating temperature is set to be 550°C or lower. The reheating temperature is preferably 520°C or lower, more preferably 500°C or lower, and still more preferably 450°C or lower.

[0062] In the present invention, "reheating" means, as it is stated, heating, that is, raising the temperature from the above cooling stop temperature T. Accordingly, the reheating temperature is a temperature higher than the above cooling stop temperature T. Therefore, even if the reheating temperature is, for example, within a temperature region of 100°C or higher and 550°C or lower, this does not fall under the category of the reheating of the present invention if the cooling stop temperature T and the reheating temperature are the same as each other or if the reheating temperature is lower than the cooling stop temperature T.

[0063] After the steel sheet is reheated to the temperature region of higher than the cooling stop temperature T°C to 550°C or lower, the steel sheet is held in the temperature region for 50 seconds or more. When the reheating holding time is less than 50 seconds, the MA structure is excessively generated, and the ductility cannot be improved. Further, the MA structure becomes coarse, and the average circle-equivalent diameter cannot be appropriately controlled, so that the stretch-flangeability cannot be improved either. Also, the ratio V_{MA}/V_{γ} of the area ratio V_{MA} of the MA structure to the volume ratio V_{γ} of the retained γ cannot be appropriately controlled, so that the crashworthiness cannot be improved either. Furthermore, the hard phase cannot be sufficiently tempered, and also the transformation of untransformed austenite to bainitic ferrite or bainite does not proceed sufficiently. Accordingly, in the present invention, the reheating holding time is set to be 50 seconds or more. The reheating holding time is preferably 80 seconds or more, more preferably 100 seconds or more, and still more preferably 200 seconds or more. An upper limit of the reheating holding time is not particularly limited. However, when the holding time is long, the productivity decreases, and the tensile strength tends to decrease. From such viewpoints, the reheating holding time is preferably set to be 1500 seconds or less, more preferably 1000 seconds or less.

[0064] After the steel sheet is reheated and held, the steel sheet is cooled to room temperature. An average cooling rate during the cooling is not particularly limited; however, the average cooling rate is preferably, for example, 0.1°C/sec or more, more preferably 0.4°C/sec or more. Further, the average cooling rate is preferably, for example, 200°C/sec or less, more preferably 150°C/sec or less.

[Plating treatment]

[0065] After the reheating holding, the high-strength cold-rolled steel sheet according to the present invention obtained by cooling to room temperature may be subjected to electro galvanization, hot-dip galvanizing, or hot-dip galvannealing

in accordance with a conventional method.

[0066] The electro galvanization may be carried out, for example, by subjecting the above high-strength cold-rolled steel sheet to energization while immersing the steel sheet into a zinc solution of 50 to 60°C (particularly 55°C) so as to perform an electrogalvanization treatment. The plating adhesion amount is not particularly limited and may be, for example, about 10 to 100 g/m^2 per one surface.

[0067] The hot-dip galvanizing may be carried out, for example, by immersing the above high-strength cold-rolled steel sheet into a hot-dip galvanizing bath of 300°C or higher and 550°C or lower, so as to perform a hot-dip galvanizing treatment. The plating time may be suitably adjusted so that a desired plating adhesion amount can be ensured. The plating time is preferably set to be, for example, 1 to 10 seconds.

[0068] The hot-dip galvannealing may be carried out by performing an alloying treatment after the above hot-dip galvanizing. The alloying treatment temperature is not particularly limited; however, when the alloying treatment temperature is too low, the alloying does not proceed sufficiently, so that the alloying treatment temperature is preferably 450°C or higher, more preferably 460°C or higher, and still more preferably 480°C or higher. However, when the alloying treatment temperature is too high, the alloying proceeds too much, and the Fe concentration in the plating layer becomes high, thereby deteriorating the plating adhesion property. From such a viewpoint, the alloying treatment temperature is preferably 550°C or lower, more preferably 540°C or lower, and still more preferably 530°C or lower. The alloying treatment time is not particularly limited and may be adjusted so that the hot-dip galvanized layer may be alloyed. The alloying treatment time is preferably, for example, 10 to 60 seconds.

[0069] A high-strength hot-dip galvanized steel sheet having a tensile strength of 980 MPa or more and being excellent in formability and crashworthiness according to the present invention can also be produced by subjecting a steel satisfying a component composition described above to hot rolling with a rolling rate at a final stand of finish rolling being 5 to 25% and with a finish rolling end temperature being the Ar_3 point or higher and 900°C or lower, coiling with a coiling temperature being 600°C or lower, and cooling to room temperature; cold rolling; heating, at an average heating rate of 10°C/second or more, to a temperature region of the Ac_3 point or higher, and soaking by holding in the temperature region for 50 seconds or more; cooling at an average cooling rate of 10°C/second or more, to an arbitrary cooling stop temperature T°C that lies in a temperature range of 100°C or higher and the Ms point or lower; and heating and holding in a temperature region of higher than the cooling stop temperature T°C to 550°C or lower for 50 seconds or more, and after performing hot-dip galvanizing within a holding time, cooling to room temperature. In other words, the steps until heating to the temperature region of higher than the cooling stop temperature T°C to 550°C or lower are the same as those of the above-described method for producing a high-strength cold-rolled steel sheet according to the present invention, so that the hot-dip galvanizing and the holding for 50 seconds or more that is carried out in the above temperature region of higher than the cooling stop temperature T°C to 550°C or lower may be simultaneously carried out in the same step.

[0070] The hot-dip galvanizing may be carried out within the holding time in the reheating temperature region, that is, in the temperature region of higher than the cooling stop temperature T°C to 550°C or lower, and a conventional method can be adopted as a specific plating method. For example, the steel sheet heated to the temperature region of higher than the cooling stop temperature T°C to 550°C or lower may be immersed into a plating bath adjusted to have a temperature within the range of higher than the cooling stop temperature T°C to 550°C or lower, so as to perform a hot-dip galvanizing treatment. The plating time may be suitably adjusted so that a desired plating amount can be ensured within the time of the reheating holding. The plating time is preferably set to be, for example, 1 to 10 seconds.

[0071] There are the following three patterns of (I) to (III) as a combination of the hot-dip galvanizing treatment; and only the heating and without performing the plating treatment, in the reheating.

(I) Only the heating is carried out, and thereafter, the hot-dip galvanizing treatment is carried out.
(II) The hot-dip galvanizing treatment is carried out, and thereafter, only the heating is carried out.
(III) Only the heating is carried out, and thereafter, the hot-dip galvanizing treatment is carried out, and further, only the heating is carried out, in this order.

[0072] The reheating temperature at which only the heating is carried out and the temperature of the plating bath used for performing the hot-dip galvanizing may be different from each other. In the present invention, heating or cooling may be carried out from one temperature to the other temperature. Furnace heating, induction heating, or the like may be adopted as a method for the heating.

[0073] A high-strength hot-dip galvannealed steel sheet having a tensile strength of 980 MPa or more and being excellent in formability and crashworthiness according to the present invention can also be produced by subjecting a steel satisfying a component composition described above to hot rolling with a rolling rate at a final stand of finish rolling being 5 to 25% and with a finish rolling end temperature being the Ar_3 point or higher to 900°C or lower, coiling with a coiling temperature being 600°C or lower, and cooling to room temperature; cold rolling; heating, at an average heating rate of 10°C/second or more, to a temperature region of the Ac_3 point or higher, and soaking by holding in the temperature region for 50 seconds or more; cooling at an average cooling rate of 10°C/second or more, to an arbitrary cooling stop

temperature T°C that lies in a temperature range of 100°C or higher and the Ms point or lower; and heating and holding in a temperature region of higher than the cooling stop temperature T°C to 550°C or lower for 50 seconds or more, and after performing hot-dip galvanizing within a holding time, further performing an alloying treatment and thereafter cooling to room temperature. In other words, the steps until heating to the temperature region of higher than the cooling stop temperature T°C to 550°C or lower are the same as those of the above-described method for producing a high-strength cold-rolled steel sheet according to the present invention, so that the hot-dip galvanizing and the holding for 50 seconds or more that is carried out in the above temperature region of higher than the cooling stop temperature T°C to 550°C or lower may be simultaneously carried out in the same step, and thereafter the hot-dip galvanized layer may be alloyed, followed by cooling down to room temperature.

[0074] The alloying treatment temperature is not particularly limited; however, when the alloying treatment temperature is too low, the alloying does not proceed sufficiently, so that the alloying treatment temperature is preferably 450°C or higher, more preferably 460°C or higher, and still more preferably 480°C or higher. However, when the alloying treatment temperature is too high, the alloying proceeds too much, and the Fe concentration in the plating layer becomes high, thereby deteriorating the plating adhesion property. From such a viewpoint, the alloying treatment temperature is preferably 550°C or lower, more preferably 540°C or lower, and still more preferably 530°C or lower.

[0075] The alloying treatment time is not particularly limited and may be adjusted so that the hot-dip galvanized layer may be alloyed. The alloying treatment time is preferably, for example, 10 to 60 seconds. The alloying treatment is carried out after performing the hot-dip galvanizing treatment for a predetermined period of time within the temperature region of higher than the cooling stop temperature T°C to 550°C or lower, so that the time needed for the alloying treatment is not included in the holding time within the temperature region of higher than the cooling stop temperature T°C to 550°C or lower.

[0076] After performing the hot-dip galvanizing within the holding time in the temperature region of higher than the cooling stop temperature T°C to 550°C or lower and performing the alloying treatment in accordance with the needs, the steel sheet may be cooled down to room temperature. The average cooling rate during the cooling is not particularly limited; however, the average cooling rate is preferably, for example, 0.1°C/sec or more, more preferably 0.4°C/sec or more. Further, the average cooling rate is preferably, for example, 200°C/sec or less, more preferably 150°C/sec or less.

[0077] The high-strength cold-rolled steel sheet according to the present invention has a tensile strength of 980 MPa or more. The tensile strength is preferably 1000 MPa or more, more preferably 1010 MPa or more. Further, the above high-strength cold-rolled steel sheet is excellent in formability as evaluated by ductility and stretch-flangeability, and also is excellent in crashworthiness.

[0078] The ductility can be evaluated by strength - elongation balance. In the present invention, those in which a product of the tensile strength TS (MPa) and the elongation EL (%) is 13000 MPa·% or more are rated as acceptable. The value of TS × EL is preferably 13100 MPa·% or more, more preferably 13200 MPa·% or more.

[0079] The stretch-flangeability can be evaluated by strength - hole expansion ratio balance. In the present invention, those in which a product of the tensile strength TS (MPa) and the hole expansion ratio λ (%) is 40000 MPa·% or more are rated as acceptable. The value of TS × λ is preferably 41000 MPa·% or more, more preferably 42000 MPa·% or more.

[0080] The crashworthiness can be evaluated by strength-VDA bending angle balance. In the present invention, those in which a product of the tensile strength TS (MPa) and the VDA bending angle (°) is 90000 MPa·° or more are rated as acceptable. The value of TS × VDA bending angle is preferably 90500 MPa·° or more, more preferably 91000 MPa·° or more.

[0081] The thickness of the high-strength cold-rolled steel sheet according to the present invention is not particularly limited; however, the steel sheet is preferably a thin steel sheet having a thickness of, for example, 6 mm or less.

[0082] The present application claims the rights of priority based on Japanese Patent Application No. 2015-071437 filed on March 31, 2015 and Japanese Patent Application No. 2015-225506 filed on November 18, 2015. The entire contents of the specifications of Japanese Patent Application No. 2015-071437 and Japanese Patent Application No. 2015-225506 are incorporated in the present application by reference.

Examples

[0083] Hereafter, the present invention will be described more specifically by way of Examples; however, the invention is not limited by the following Examples and can be carried out while including additional modifications within a scope conforming to the gist disclosed heretofore and hereinafter, all such modifications being encompassed within the technical scope of the invention.

[0084] A steel containing the components given in the following Table 1 with the balance being iron and inevitable impurities was prepared by ingot-making and subjected to hot rolling, cold rolling, and continuous annealing to produce a cold-rolled steel sheet. In the following Table 1, "-" means that the corresponding element is not contained. The following Table 1 also show the temperature of the Ar_3 point calculated on the basis of the above formula (ii) and the temperature of the Ac_3 point calculated on the basis of the above formula (iii). Further, FIG. 1 shows one example of a heat treatment

pattern that was carried out in the continuous annealing. In FIG. 1, the reference sign 1 denotes a heating step, 2 a soaking step, 3 a cooling step, 4 a reheating holding step, and 5 a cooling stop temperature.

[Hot rolling]

[0085] A slab obtained by ingot-making was heated to 1250°C, and hot rolling was carried out to a sheet thickness of 2.3 mm with the rolling reduction in the final stand of finish rolling being set to be a rolling reduction shown in the following Table 2-1 or 2-2 and with the finish rolling end temperature being set to be a temperature shown in the following Table 2-1 or 2-2. After the hot rolling, the steel sheet was cooled down to a coiling temperature shown in the following Table 2-1 or 2-2 at an average cooling rate of 30°C/sec, followed by coiling. After the coiling, the steel sheet was cooled in air to room temperature, so as to produce a hot-rolled steel sheet.

[Cold rolling]

[0086] After the obtained hot-rolled steel sheet was pickled to remove surface scale, cold rolling was carried out to produce a cold-rolled steel sheet having a thickness of 1.2 mm.

[Continuous annealing]

[0087] The obtained cold-rolled steel sheet was subjected to continuous annealing based on the heat treatment pattern shown in FIG. 1. That is, the obtained cold-rolled steel sheet was heated as a heating step at an average heating rate shown in the following Table 2-1 or 2-2 up to the soaking temperature shown in the following Table 2-1 or 2-2, and was held at the soaking temperature as a soaking step. The following Table 2-1 or 2-2 shows the soaking time. Further, the following Table 2-1 or 2-2 shows a value calculated by subtracting the temperature of the Ac_3 point from the soaking temperature.

[0088] After the soaking, the steel sheet was cooled as a cooling step at an average cooling rate shown in the following Table 2-1 or 2-2 down to the cooling stop temperature T°C shown in the following Table 2-1 or 2-2.

[0089] After the cooling, the steel sheet was heated to the reheating temperature shown in the following Table 2-1 or 2-2 and was held at the reheating temperature as a reheating holding step, followed by cooling down to room temperature to produce a test sample material. The following Table 2-1 or 2-2 shows the reheating holding time. Also, the following Table 2-1 or 2-2 shows a value calculated by subtracting the cooling stop temperature T from the reheating temperature.

[0090] Further, the Ms point was calculated in accordance with the above formula (iv) based on the component composition shown in the following Table 1. The results are shown in the following Tables 2-1 and 2-2. The following Tables 2-1 and 2-2 also show a value obtained by subtracting the temperature of the Ms point from the cooling stop temperature T.

[0091] No. 11 shown in the following Table 2-1 and No. 29 shown in the following Table 2-2 are samples in which the reheating holding step was not carried out after the cooling was stopped at the cooling stop temperature T shown in the following Table 2-1 or 2-2. That is, in No. 11, the steel sheet was cooled with the cooling stop temperature T set to be 440°C, and thereafter cooled to 350°C, which was lower than that temperature, and held at 350°C for 600 seconds. For the sake of convenience, the following Table 2-1 gives 350°C in the section of the reheating temperature and gives 600 seconds in the section of the reheating holding time. In No. 29, the steel sheet was cooled with the cooling stop temperature T set to be 350°C, and thereafter cooled to 330°C, which was lower than that temperature, and held at 330°C for 300 seconds. For the sake of convenience, the following Table 2-2 gives 330°C in the section of the reheating temperature and gives 300 seconds in the section of the reheating holding time.

[Electrogalvanization]

[0092] No. 15 shown in the following Table 2-1 is a sample in which the above test sample material was immersed into a galvanizing bath of 55°C to perform an electrogalvanization treatment and thereafter washed with water and dried to produce an electrogalvanized steel sheet. The electrogalvanization treatment was carried out with an electric current density set to be 40 A/dm^2. The galvanizing adhesion amount was 40 g/m^2 per one surface. In the electrogalvanization treatment, washing treatments such as degreasing with alkaline aqueous solution immersion, washing with water, and pickling or the like were carried out as appropriate, so as to produce a test sample material having an electrogalvanized layer on the surface of the cold-rolled steel sheet. In the following Table 2-1, the section of classification for No. 15 gives "EG".

[Hot-dip galvanizing]

[0093] No. 36 shown in the following Table 2-2 is a sample in which the above test sample material was immersed into a hot-dip galvanizing bath of 460°C to perform a hot-dip galvanizing treatment, thereby to produce a hot-dip galvanized steel sheet. The hot-dip galvanizing adhesion amount was 30 g/m^2 per one surface. In the following Table 2-2, the section of classification for No. 36 gives "GI".

[Hot-dip galvannealing]

[0094] No. 6 shown in the following Table 2-1 is a sample in which the above test sample material was immersed into a hot-dip galvanizing bath of 460°C to perform a hot-dip galvanizing treatment, followed by heating to 500°C to perform an alloying treatment, thereby to produce a hot-dip galvannealed steel sheet. The hot-dip galvannealing adhesion amount was 30 g/m^2 per one surface. In the following Table 2-1, the section of classification for No. 6 gives "GA".

[0095] Test sample materials in which none of the electrogalvanization treatment, hot-dip galvanizing treatment, and hot-dip galvannealing treatment was carried out are denoted as "cold-rolled" in the section of classification in the following Tables 2-1 and 2-2.

[0096] With respect to the obtained test sample materials, a metal structure was observed by the following procedure.

[Observation of metal structure]

(Area ratio of ferrite and hard phase)

[0097] After the cross-section of the obtained test sample material was polished, the test sample material was subjected to nital corrosion, followed by performing observation at the position of 1/4 of the sheet thickness in three fields of view at a magnification of 1000 times with a scanning electron microscope, so as to capture a photomicrograph image. The observation field of view was such that one field of view had a size of 100 μm $\times$ 100 μm. With the lattice interval set to be 5 μm, the area ratio of ferrite was measured by the point counting method with the number of lattice points being 20 $\times$ 20, and an average value of the three fields of view was calculated. The calculation results are shown in the following Tables 3-1 and 3-2. The area ratio of ferrite was calculated by excluding the area ratio of the hard phase that existed in the ferrite phase.

[0098] In a similar manner, a sum area ratio of pearlite and cementite was measured by the point counting method, and an average value of the three fields of view was calculated. The calculation results are shown in the following Tables 3-1 and 3-2. The sum area ratio of pearlite and cementite is denoted as "other structures" in the following Tables 3-1 and 3-2.

[0099] In the present Examples, the structure other than ferrite, pearlite, and cementite calculated by the point counting method was assumed to be a hard phase. In other words, a value obtained by subtracting the area ratio of ferrite and the sum area ratio of pearlite and cementite from 100% was calculated as an area ratio of the hard phase. The results are shown in the following Tables 3-1 and 3-2.

[0100] As a result of observation of a specific structure constituting the hard phase, it was found out that the hard phase included quenched martensite and retained γ and included at least one selected from the group consisting of bainitic ferrite, bainite, and tempered martensite.

(Volume ratio V_γ of retained γ)

[0101] The obtained test sample material was polished down to the position of 1/4 of the sheet thickness with use of a sandpaper of #1000 to #1500, and further the surface was subjected to electrolytic polishing down to the depth of 10 to 20 μm, followed by measuring the volume ratio V_γ of retained γ with use of an X-ray diffractometer. Specifically, "RINT 1500" manufactured by Rigaku Corporation was used as the X-ray diffractometer and, with use of a Co target, a power of 40 kV - 200 mA was output to measure the range of 40° to 130° in terms of 2θ. The volume ratio V_γ of retained γ was quantitated on the basis of the obtained bcc (α) diffraction peaks (110), (200), and (211) and fcc (γ) diffraction peaks (111), (200), (220), and (311). The results are shown in the following Tables 3-1 and 3-2.

(Area ratio V_{MA} and average circle-equivalent diameter of MA structure)

[0102] After the cross-section of the obtained test sample material was polished, the test sample material was subjected to LePera corrosion, followed by performing observation at the position of 1/4 of the sheet thickness in three fields of view at a magnification of 1000 times with an optical microscope, so as to capture a photomicrograph image. The observation field of view was such that one field of view had a size of 100 μm $\times$ 100 μm. The portion whitened by LePera

corrosion was regarded as the MA structure. With the lattice interval set to be 5 μm, the area ratio of the MA structure was measured by the point counting method with the number of lattice points being 20 × 20, and an average value of the three fields of view was calculated. The calculation results are shown in the following Tables 3-1 and 3-2.

[0103] Upon subjecting the photomicrograph image captured with the optical microscope to image analysis, the average circle-equivalent diameter d of each MA structure was calculated, and an average value was determined. The results are shown in the following Tables 3-1 and 3-2.

(Ratio of area ratio V_{MA} of MA structure to volume ratio V_{γ} of retained γ)

[0104] The ratio V_{MA}/V_{γ} of the area ratio V_{MA} of the MA structure to the volume ratio V_{γ} of the retained γ was calculated on the basis of the volume ratio V_{γ} of the retained γ and the area ratio V_{MA} of the MA structure calculated by the above-described procedure. The calculation results are shown in the following Tables 3-1 and 3-2.

[0105] Next, with respect to the obtained test sample material, the mechanical properties, ductility, stretch-flangeability, and crashworthiness were evaluated by the following procedure.

[Evaluation of mechanical properties and ductility]

[0106] A No. 5 test piece defined in JIS Z2201 was cut out so that the direction perpendicular to the rolling direction of the obtained test sample material would be a longitudinal direction. With use of this test piece, a tensile test was carried out so as to measure the tensile strength TS and the elongation EL. The measurement results are shown in the following Tables 3-1 and 3-2.

[0107] In the present Examples, the samples in which the tensile strength was 980 MPa or more were evaluated as having a high strength and being acceptable, whereas the samples in which the tensile strength was less than 980 MPa were evaluated as having an insufficient strength and being a reject.

[0108] Also, the value of tensile strength TS × elongation EL was calculated on the basis of the measured values of tensile strength TS and elongation EL. The calculation results are shown in the following Tables 3-1 and 3-2. The value of TS × EL indicates a strength - elongation balance and serves as an index for evaluating the ductility.

[0109] In the present Examples, the samples in which the value of TS × EL was 13000 MPa·% or more were evaluated as having an excellent ductility and being acceptable, whereas the samples in which the value of TS × EL was less than 13000 MPa·% were evaluated as having a poor ductility and being a reject.

[Evaluation of stretch-flangeability]

[0110] In order to evaluate the stretch-flangeability of the test sample material, a hole expansion test was carried out according to the Japan Iron and Steel Federation Standard JFS T 1001, so as to measure the hole expansion ratio λ. The measurement results are shown in the following Tables 3-1 and 3-2.

[0111] Also, the value of tensile strength TS × hole expansion ratio λ was calculated on the basis of the measured values of tensile strength TS and hole expansion ratio λ. The calculation results are shown in the following Tables 3-1 and 3-2. The value of TS × λ indicates a strength - hole expansion ratio balance and serves as an index for evaluating the stretch-flangeability.

[0112] In the present Examples, the samples in which the value of TS × λ was 40000 MPa·% or more were evaluated as having an excellent stretch-flangeability and being acceptable, whereas the samples in which the value of TS × λ was less than 40000 MPa·% were evaluated as having a poor stretch-flangeability and being a reject.

[Evaluation of crashworthiness]

[0113] It is disclosed in the following literature that the crashworthiness is correlated to a bending angle.

[0114] Literature: P. Larour, H. Pauli, T. Kurz, T. Hebesberger: "Influence of post uniform tensile and bending properties on the crash behaviour of AHSS and press-hardening steel grades", IDDRG2010

[0115] Accordingly, a bending test was carried out under the following conditions on the basis of the VDA standard (VDA238-100) defined by the German Association of the Automotive Industry. The displacement at the maximum load measured by the bending test was converted into an angle according to the VDA standard, so as to determine the bending angle. The conversion results are shown in the following Tables 3-1 and 3-2.

(Measurement conditions)

[0116]

Test method: support with rolls, pressing-in of punch
Roll diameter: ϕ30 mm
Punch shape: tip end R = 0.4 mm
Distance between rolls: 2.9 mm
Punch pressing-in speed: 20 mm/min
Test piece dimension: 60 mm × 60 mm
Bending direction: direction perpendicular to the rolling direction
Testing machine: SIMAZU AUTOGRAPH 20 kN

[0117] Also, the value of tensile strength TS × VDA bending angle° was calculated on the basis of the values of the tensile strength TS measured in the tensile test and the VDA bending angle. The calculation results are shown in the following Tables 3-1 and 3-2.

[0118] In the present Examples, the samples in which the value of TS × VDA was 90000 MPa·° or more were evaluated as having an excellent crashworthiness and being acceptable, whereas the samples in which the value of TS × VDA was less than 90000 MPa·° were evaluated as having a poor crashworthiness and being a reject.

[0119] On the basis of the above results, samples satisfying all of the requirements: the value of TS being 980 MPa or more, the value of TS × EL being 13000 MPa·% or more, the value of TS × λ being 40000 MPa·% or more, and the value of TS × VDA being 90000 MPa·° or more were regarded as the present invention examples and listed as being acceptable in the total evaluation section of the following Tables 3-1 and 3-2. On the other hand, samples in which one or more of the value of TS, the value of TS × EL, the value of TS × λ, and the value of TS × VDA failed to satisfy the above acceptance standard were regarded as the comparative examples and listed as being a reject in the total evaluation section of the following Tables 3-1 and 3-2.

[Table 1]

Steel type	Component (mass %)																		Ar3 point (°C)	Ac3 point (°C)
	C	Si	Mn	P	S	Al	Cr	Mo	Ti	Nb	V	Cu	Ni	B	Ca	Mg	REM	N	O	
A	0.19	1.53	2.38	0.02	0.002	0.02	-	-	-	-	-	-	-	-	-	-	-	0.003	0.002	660	840
B	0.23	2.55	2.18	0.04	0.001	0.03	-	-	-	-	-	-	-	-	-	-	-	0.004	0.001	664	901
C	0.16	1.56	2.09	0.02	0.001	0.03	-	-	-	-	-	-	-	-	-	-	-	0.005	0.001	694	862
D	0.25	2.25	2.34	0.05	0.002	0.02	0.1	-	-	-	-	-	-	-	-	-	-	0.004	0.001	644	881
E	0.18	2.39	1.85	0.02	0.001	0.02	-	0.2	-	-	-	-	-	-	-	-	-	0.003	0.002	690	903
F	0.29	1.97	2.34	0.04	0.001	0.01	-	-	0.08	-	-	-	-	-	-	-	-	0.002	0.001	634	883
G	0.41	2.35	2.00	0.04	0.001	0.03	-	-	-	0.07	-	-	-	-	-	-	-	0.002	0.002	622	865
H	0.12	1.76	2.22	0.05	0.001	0.03	-	-	-	-	0.10	-	-	-	-	-	-	0.003	0.001	697	911
I	0.13	2.01	2.29	0.01	0.002	0.01	-	-	-	-	-	0.10	0.10	-	-	-	-	0.002	0.001	680	866
J	0.20	1.07	2.30	0.02	0.002	0.02	-	-	-	-	-	-	-	0.0024	-	-	-	0.005	0.001	664	820
K	0.24	1.37	2.40	0.03	0.003	0.01	-	-	-	-	-	-	-	-	0.0015	-	-	0.004	0.002	643	824
L	0.19	2.73	2.13	0.01	0.002	0.03	-	-	-	-	-	-	-	-	-	0.0019	-	0.005	0.001	681	899
M	0.22	2.89	2.00	0.02	0.001	0.01	-	-	-	-	-	-	-	-	-	-	0.0030	0.003	0.002	682	902
N	0.18	2.14	1.55	0.01	0.003	0.03	-	-	-	-	-	-	-	-	-	-	-	0.005	0.002	731	893
O	0.20	2.25	1.72	0.01	0.001	0.03	-	-	-	-	-	-	-	-	-	-	-	0.003	0.001	709	887
P	0.21	2.32	2.89	0.05	0.001	0.02	-	-	-	-	-	-	-	-	-	-	-	0.002	0.001	613	877
Q	0.16	1.83	4.67	0.01	0.003	0.01	-	-	-	-	-	-	-	-	-	-	-	0.002	0.002	488	783
R	0.24	1.89	6.22	0.03	0.002	0.02	-	-	-	-	-	-	-	-	-	-	-	0.002	0.002	339	738
S	0.07	1.59	2.57	0.03	0.003	0.03	-	-	-	-	-	-	-	-	-	-	-	0.004	0.002	684	885
T	0.17	0.58	2.50	0.02	0.002	0.01	-	-	-	-	-	-	-	-	-	-	-	0.005	0.001	659	796
U	0.17	2.15	1.18	0.03	0.002	0.01	-	-	-	-	-	-	-	-	-	-	-	0.002	0.001	762	912

[Table 2-1]

No.	Steel type	Hot rolling step			Annealing step											Classification
					Heating	Soaking			Cooling				Reheating holding			
		Finish rolling end temperature (°C)	Final stand rolling rate (%)	Coiling temperature (°C)	Average heating rate (°C/sec)	Soaking temperature (°C)	Soaking temperature -Ac_3 point (°C)	Soaking time (sec)	Average cooling rate (°C/sec)	Cooling stop temperature T (°C)	Ms point (°C)	Cooling stop temperature T -Ms point (°C)	Reheating temperature (°C)	Reheating temperature -cooling stop temperature T (°C)	Reheating holding time (sec)	
1	A	880	15	500	15	870	30	300	15	190	391	-201	300	110	600	Cold -rolled
2	A	880	15	500	15	870	30	300	15	25	391	-366	400	375	600	Cold-rolled
3	A	880	10	550	2	910	70	550	10	350	391	-41	420	70	600	Cold-rolled
4	A	880	10	550	15	910	70	300	10	420	391	29	450	30	600	Cold-rolled
5	B	850	15	550	10	910	9	300	15	280	379	-99	380	100	600	Cold-rolled
6	B	850	15	550	10	910	9	300	15	250	379	-129	440	190	300	GA
7	B	1000	15	550	10	910	9	300	15	330	379	-49	440	110	600	Cold-rolled
8	B	880	15	700	10	910	9	300	15	360	379	-19	420	60	600	Cold-rolled
9	B	880	15	550	10	910	9	300	1	360	379	-19	420	60	600	Cold-rolled
10	C	880	15	550	15	880	18	400	15	370	417	-47	420	50	600	Cold-rolled
11	C	880	15	550	15	880	18	400	15	440	417	23	350	-90	600	Cold-rolled
12	D	880	15	550	10	910	29	300	15	220	364	-144	350	130	600	Cold-rolled
13	D	880	35	550	10	910	29	300	15	300	364	-64	430	130	600	Cold-rolled
14	D	880	3	550	10	910	29	300	15	350	364	-14	460	110	600	Cold-rolled
15	E	880	7	500	10	910	7	300	10	300	409	-109	440	140	600	EG
16	E	880	7	500	10	840	-63	300	10	300	409	-109	440	140	600	Cold-rolled
17	F	880	20	550	15	900	17	300	15	200	347	-147	300	100	600	Cold-rolled
18	G	880	20	550	15	880	15	300	15	180	300	-120	250	70	600	Cold-rolled
19	H	880	15	550	15	920	9	300	15	300	433	-133	400	100	600	Cold-rolled
20	I	880	15	550	15	910	44	300	15	250	423	-173	350	100	600	Cold-rolled

[Table 2-2]

No.	Steel type	Hot rolling step			Annealing step											Classification
					Heating	Soaking			Cooling				Reheating holding			
		Finish rolling end temperature (°C)	Final stand rolling rate (%)	Coiling temperature (°C)	Average heating rate (°C/sec)	Soaking temperature (°C)	Soaking temperature -Ac_3 point (°C)	Soaking time (sec)	Average rate (°C/sec)	Cooling stop temperature T (°C)	Ms point (°C)	Cooling stop temperature T -Ms point (°C)	Reheating temperature (°C)	Reheating temperature -cooling stop temperature T (°C)	Reheating holding time (sec)	
21	J	880	15	550	15	850	30	300			391	-141	330	330	600	Cold-rolled
22	K	880	10	550	15	880	56	300	20	200	367	-167	220	20	600	Cold-rolled
23	K	880	10	550	15	880	56	300	20	350	367	-17	500	150	5	Cold-rolled
24	K	880	15	550	15	880	56	300	20	350	367	-17	650	300	1000	Cold-rolled
25	L	880	15	500	15	910	11	300	20	200	401	-201	250	50	600	Cold-rolled
26	M	880	15	500	15	930	28	300	20	250	392	-142	300	50	600	Cold-rolled
27	N	880	15	450	15	910	17	300	20	250	426	-176	300	50	600	Cold -rolled
28	O	880	15	450	15	900	13	300	20	250	408	-158	350	100	600	Cold -rolled
29	O	880	30	450	15	900	13	300	15	350	408	-58	330	-20	300	Cold-rolled
30	P	880	15	550	15	900	23	300	15	250	366	-116	400	150	600	Cold-rolled
31	Q	880	15	550	15	850	67	300	10	300	333	-33	500	200	1000	Cold-rolled
32	R	880	15	550	15	850	112	300	10	200	244	-44	500	300	1000	Cold-rolled
33	s	880	15	550	15	900	15	300	10	300	445	-145	400	100	600	Cold-rolled
34	T	880	15	550	15	880	84	300	10	250	400	-150	300	50	600	Cold-rolled
35	U	880	15	550	15	930	18	300	10	400	441	-41	500	100	600	Cold-rolled
36	A	880	15	500	15	870	30	550	30	250	391	-141	420	170	600	GI
37	P	880	15	550	15	900	23	300	15	350	366	-16	450	100	300	Cold-rolled
38	C	880	15	600	7	910	48	450	10	400	417	-17	450	50	300	Cold-rolled
39	A	880	15	500	15	850	10	300	7	370	391	-21	430	60	200	Cold-rolled
40	B	850	15	550	15	910	9	300	15	140	379	-239	180	40	600	Cold-rolled

(continued)

No.	Steel type	Hot rolling step			Annealing step											Classification
					Heating	Soaking			Cooling				Reheating holding			
		Finish rolling end temperature (°C)	Final stand rolling rate (%)	Coiling temperature (°C)	Average heating rate (°C/sec)	Soaking temperature (°C)	Soaking temperature -Ac_3 point (°C)	Soaking time (sec)	Average rate (°C/sec)	Cooling stop temperature T (°C)	Ms point (°C)	Cooling stop temperature T -Ms point (°C)	Reheating temperature (°C)	Reheating temperature -cooling stop temperature T (°C)	Reheating holding time (sec)	
41	N	880	15	550	15	910	17	300	20	70	426	-356	380	310	600	Cold-rolled
42	C	880	15	550	15	880	18	300	15	250	417	-167	370	120	100	Cold-rolled
43	B	900	15	500	15	910	9	100	20	230	379	-149	400	170	600	Cold-rolled

[Table 3-1]

No.	Structure fraction					Average circle-equivalent diameter of MA structure (μm)	V_{MA}/V_{γ}	Material properties							
	Ferrite (area%)	Hard phase (area%)	Other structures (area%)	Retained γ V_{γ} (vol%)	MA structure V_{MA} (area%)			TS (MPa)	EL (%)	λ (%)	VDA (°)	TS×EL (MPa·%)	TS×λ (MPa·%)	TS×VDA (MPa·°)	Total evaluation
1	1	95	4	6	7	1.0	1.17	1306	11	52	75	14366	67912	97950	Acceptable
2	2	95	3	3	1	0.7	0.33	1421	6	39	68	8526	55419	96628	Reject
3	5	91	4	10	12	2.2	1.20	1042	14	34	91	14588	35428	94822	Reject
4	4	94	2	11	15	2.7	1.36	993	15	32	83	14895	31776	82419	Reject
5	3	94	3	10	11	1.2	1.10	1321	12	38	72	15852	50198	95112	Acceptable
6	3	94	3	11	14	1.4	1.27	1125	15	42	83	16875	47250	93375	Acceptable
7	4	93	3	12	17	2.3	1.42	1295	12	26	70	15540	33670	90650	Reject
8	3	92	5	14	19	2.4	1.36	1226	12	24	74	14712	29424	90724	Reject
9	28	65	7	16	21	1.8	1.31	1104	19	17	84	20976	18768	92736	Reject
10	3	94	3	10	13	1.1	1.30	1021	15	61	104	15315	62281	106184	Acceptable
11	3	95	2	8	15	1.7	1.88	1012	14	51	83	14168	51612	83996	Reject
12	3	94	3	7	9	1.2	1.29	1423	10	32	66	14230	45536	93918	Acceptable
13	6	90	4	10	12	2.5	1.20	1287	11	25	65	14157	32175	83655	Reject
14	4	94	2	11	15	2.2	1.36	1154	13	29	79	15002	33466	91166	Reject
15	3	95	2	11	13	1.3	1.18	1056	15	51	89	15840	53856	93984	Acceptable
16	32	65	3	14	19	1.5	1.36	991	23	24	92	22793	23784	91172	Reject
17	2	96	2	11	14	1.4	1.27	1352	12	31	70	16224	41912	94640	Acceptable
18	2	96	2	13	15	1.7	1.15	1546	9	28	60	13914	43288	92760	Acceptable
19	1	97	2	7	8	1.2	1.14	1032	14	52	91	14448	53664	93912	Acceptable
20	3	93	4	8	9	1.1	1.13	1153	13	42	82	14989	48426	94546	Acceptable

[Table 3-2]

No.	Structure fraction					Average circle-equivalent diameter of MA structure (μm)	V_{MA}/V_{γ}	Material properties							
	Ferrite (area%)	Hard phase (area%)	Other structures (area%)	Retained γ V_{γ} (vol%)	MA structure V_{MA} (area%)			TS (MPa)	EL (%)	λ (%)	VDA (°)	TS × EL (MPa·%)	TS × λ (MPa·%)	TS × VDA (MPa·°)	Total evaluation
21	2	97	1	7	8	1.4	1.14	1232	12	40	80	14784	49280	98560	Acceptable
22	1	97	2	5	6	1.0	1.20	1510	10	31	63	15100	46810	95130	Acceptable
23	1	97	2	14	53	4.3	3.79	1642	5	8	31	8210	13136	50902	Reject
24	2	82	16	2	2	0.9	1.00	846	11	19	79	9306	16074	66834	Reject
25	2	94	4	8	9	1.2	1.13	1373	11	32	68	15103	43936	93364	Acceptable
26	5	93	2	9	10	1.4	1.11	1298	11	37	71	14278	48026	92158	Acceptable
27	6	91	3	7	8	1.3	1.14	1193	13	41	78	15509	48913	93054	Acceptable
28	4	94	2	8	9	1.3	1.13	1104	14	46	84	15456	50784	92736	Acceptable
29	3	95	2	6	11	2.3	1.83	1337	11	23	58	14707	30751	77546	Reject
30	1	97	2	8	9	1.2	1.13	1125	13	45	83	14625	50625	93375	Acceptable
31	0	98	2	6	8	1.6	1.33	1218	12	38	79	14616	46284	96222	Acceptable
32	0	97	3	7	8	0.9	1.14	1339	10	32	69	13390	42848	92391	Acceptable
33	2	96	2	4	4	1.4	1.00	1092	10	55	88	10920	60060	96096	Reject
34	0	97	3	2	3	1.0	1.50	1274	7	42	72	8918	53508	91728	Reject
35	18	74	8	10	12	1.8	1.20	991	15	29	95	14865	28739	94145	Reject
36	3	94	3	8	11	1.4	1.38	1103	15	41	92	16545	45223	101476	Acceptable
37	5	93	2	21	24	1.7	1.14	1004	15	42	95	15060	42168	95380	Acceptable
38	5	93	2	13	18	2.2	1.38	991	16	39	94	15856	38649	93154	Reject
39	23	74	3	8	11	1.9	1.38	1162	13	15	79	15106	17430	91798	Reject
40	3	95	2	6	5	0.9	0.83	1536	10	31	62	15360	47616	95232	Acceptable
41	3	95	2	4	3	1.0	0.75	1052	11	68	87	11572	71536	91524	Reject
42	6	92	2	6	4	0.8	0.67	1294	11	54	71	14234	69876	91874	Acceptable

(continued)

No.	Structure fraction					Average circle-equivalent diameter of MA structure (μm)	V_{MA}/V_{γ}	Material properties							Total evaluation
	Ferrite (area%)	Hard phase (area%)	Other structures (area%)	Retained γ V_{γ} (vol%)	MA structure V_{MA} (area%)			TS (MPa)	EL (%)	λ (%)	VDA (°)	TS × EL (MPa·%)	TS × λ (MPa·%)	TS × VDA (MPa·°)	
43	4	92	4	8	10	1.0	1.25	1253	13	42	77	16289	52626	96481	Acceptable

[0120] From Tables 1, 2-1, 2-2, 3-1, and 3-2, the following considerations can be made.

[0121] In Tables 3-1 and 3-2, all of the samples rated as "acceptable" in the total evaluation section are steel sheets satisfying the requirements defined in the present invention, and all of the value of TS × EL, the value of TS × λ, and the value of TS × VDA determined in accordance with the tensile strength TS satisfy the acceptance standard values. It will be understood that these steel sheets have good formability as evaluated by ductility and stretch-flangeability, and are excellent in stretch-flangeability in particular, and also in crashworthiness.

[0122] In contrast, the samples rated as "reject" in the total evaluation section are steel sheets that do not satisfy one or more of the requirements defined in the present invention, and at least one of ductility, stretch-flangeability, and crashworthiness could not be improved. The details are as follows.

[0123] No. 2 is a sample in which a predetermined amount of retained γ and the MA structure could not be ensured because the cooling stop temperature T after the soaking was an extremely low temperature of 25°C which was lower than 100°C, so that the value of V_{MA}/V_{γ} was below the defined range. As a result, the value of TS × EL was small, so that the ductility could not be improved.

[0124] Nos. 3 and 38 are samples in which the MA structure was coarsened because the average heating rate after the coiling was too small. As a result, the value of TS × λ was small, so that the stretch-flangeability could not be improved.

[0125] No. 4 is a sample in which the MA structure was coarsened because the cooling stop temperature T after the soaking was too high and exceeded the temperature region of 100°C or higher and the Ms point or lower. As a result, the value of TS × λ was small, so that the stretch-flangeability could not be improved. Also, the value of TS × VDA was small, so that the crashworthiness could not be improved.

[0126] No. 7 is a sample in which the MA structure was coarsened because the finish rolling end temperature was too high. As a result, the value of TS × λ was small, so that the stretch-flangeability could not be improved.

[0127] No. 8 is a sample in which the MA structure was coarsened because the coiling temperature was too high. As a result, the value of TS × λ was small, so that the stretch-flangeability could not be improved.

[0128] Nos. 9 and 39 are samples in which ferrite was excessively generated because the average cooling rate after the soaking was too small. As a result, the value of TS × λ was small, so that the stretch-flangeability could not be improved.

[0129] No. 11 is a sample in which the value of V_{MA}/V_{γ} was too large because the cooling stop temperature T after the soaking was too high and exceeded the temperature region of 100°C or higher and the Ms point or lower and because the reheating holding was not carried out after the cooling. As a result, the value of TS × VDA was small, so that the crashworthiness could not be improved.

[0130] No. 13 is a sample in which the MA structure was coarsened because the rolling reduction at the final stand during the finish rolling was too high and exceeded the range defined in the present invention. As a result, the value of TS × λ was small, so that the stretch-flangeability could not be improved. Also, the value of TS × VDA was small, so that the crashworthiness could not be improved.

[0131] No. 14 is a sample in which the MA structure was coarsened because the rolling reduction at the final stand during the finish rolling was too low and was below the range defined in the present invention. As a result, the value of TS × λ was small, so that the stretch-flangeability could not be improved.

[0132] No. 16 is a sample in which ferrite was excessively generated because the soaking was carried out at a temperature below the AC_3 point. As a result, the value of TS × λ was small, so that the stretch-flangeability could not be improved.

[0133] No. 23 is a sample in which the MA structure was coarsened because the reheating holding time was too short. As a result, the value of TS × λ was small, so that the stretch-flangeability could not be improved. Further, the MA structure was generated excessively. As a result, the value of TS × EL was small, so that the ductility could not be improved. Also, the value of V_{MA}/V_{γ} was too large. As a result, the value of TS × VDA was small, so that the crashworthiness was deteriorated.

[0134] No. 24 is a sample in which decomposition of austenite occurred and a predetermined amount of retained γ and the MA structure could not be ensured because the reheating temperature carried out after the cooling was too high. As a result, TS was small.

[0135] No. 29 is a sample in which the MA structure was coarsened and the value of V_{MA}/Y_{γ} was too large because the rolling reduction at the final stand during the finish rolling was too high and exceeded the range defined in the present invention and because the reheating holding was not carried out after the cooling. As a result, the value of TS × λ was small, so that the stretch-flangeability could not be improved. Further, the value of TS × VDA was small, so that the crashworthiness could not be improved.

[0136] No. 33 is a sample in which the C amount was too small, so that a retained γ amount within the range defined in the present invention could not be ensured. As a result, the value of TS × EL was small, so that the ductility was deteriorated.

[0137] No. 34 is a sample in which the Si amount was too small, so that a retained γ amount within the range defined in the present invention could not be ensured. As a result, the value of TS × EL was small, so that the ductility was deteriorated.

[0138] No. 35 is a sample in which the Mn amount was too small, so that the hardenability was insufficient, and ferrite was excessively generated. As a result, the value of TS × λ was small, so that the stretch-flangeability was deteriorated.

[0139] No. 41 is a sample in which a predetermined amount of retained γ could not be ensured because the cooling stop temperature T after the soaking was below 100°C. As a result, the value of TS × EL was small, so that the ductility could not be improved.

Reference Signs

[0140]

1 Heating step
2 Soaking step
3 Cooling step
4 Reheating holding step
5 Cooling stop temperature

Claims

1. A high-strength cold-rolled steel sheet having a tensile strength of 980 MPa or more and being excellent in formability and crashworthiness, the high-strength cold-rolled steel sheet comprising, in mass%:

C: 0.10% or more to 0.5% or less,
Si: 1.0% or more to 3% or less,
Mn: 1.5% or more to 7% or less,
P: more than 0% to 0.1% or less,
S: more than 0% to 0.05% or less,
Al: 0.005% or more to 1% or less,
N: more than 0% to 0.01% or less, and
O: more than 0% to 0.01% or less,
with a balance being iron and inevitable impurities, wherein
a metal structure at a position of 1/4 of a sheet thickness satisfies (1) to (4) below:

(1) when the metal structure is observed with a scanning electron microscope, an area ratio of ferrite relative to a whole of the metal structure is 0% or more to 10% or less, with a balance being a hard phase including quenched martensite and retained austenite and including at least one selected from the group consisting of bainitic ferrite, bainite, and tempered martensite,
(2) when the metal structure is measured by X-ray diffractometry, a volume ratio V_γ of retained austenite relative to the whole of the metal structure is 5% or more to 30% or less,
(3) when the metal structure is observed with an optical microscope, an area ratio V_{MA} of an MA structure, in which quenched martensite and retained austenite are combined, relative to the whole of the metal structure is 3% or more to 25% or less, and an average circle-equivalent diameter of the MA structure is 2.0 μm or less, and
(4) a ratio V_{MA}/V_γ of the area ratio V_{MA} of the MA structure to the volume ratio V_γ of the retained austenite satisfies a formula (i) below:

$$0.50 \leq V_{MA}/V_\gamma \leq 1.50 \quad \cdots(\mathrm{i}).$$

2. The high-strength cold-rolled steel sheet according to claim 1, further comprising, as other elements, one or more of any of (a) to (e) below, in mass%:

(a) at least one selected from the group consisting of Cr: more than 0% to 1% or less and Mo: more than 0% to 1% or less,
(b) at least one selected from the group consisting of Ti: more than 0% to 0.15% or less, Nb: more than 0% to 0.15% or less, and V: more than 0% to 0.15% or less,
(c) at least one selected from the group consisting of Cu: more than 0% to 1% or less and Ni: more than 0% to

1% or less,
(d) B: more than 0% to 0.005% or less, and
(e) at least one selected from the group consisting of Ca: more than 0% to 0.01% or less, Mg: more than 0% to 0.01% or less, and REM: more than 0% to 0.01% or less.

3. A high-strength electrogalvanized steel sheet having an electrogalvanized layer on a surface of the high-strength cold-rolled steel sheet according to claim 1 or 2.

4. A high-strength hot-dip galvanized steel sheet having a hot-dip galvanized layer on a surface of the high-strength cold-rolled steel sheet according to claim 1 or 2.

5. A high-strength hot-dip galvannealed steel sheet having a hot-dip galvannealed layer on a surface of the high-strength cold-rolled steel sheet according to claim 1 or 2.

6. A method for producing a high-strength cold-rolled steel sheet having a tensile strength of 980 MPa or more and being excellent in formability and crashworthiness, the method comprising:

using a steel satisfying a component composition as set forth in claim 1 or 2,
hot rolling the steel with a rolling rate at a final stand of finish rolling being 5 to 25% and with a finish rolling end temperature being an Ar_3 point or higher to 900°C or lower, coiling the steel with a coiling temperature being 600°C or lower, and cooling the steel to room temperature,
cold rolling the steel,
heating the steel, at an average heating rate of 10°C/second or more, to a temperature region of an AC_3 point or higher, and soaking the steel while holding the steel in the temperature region for 50 seconds or more,
cooling the steel at an average cooling rate of 10°C/second or more, to an arbitrary cooling stop temperature T°C that lies in a temperature range of 100°C or higher and an Ms point or lower, and
heating and holding the steel in a temperature region of higher than the cooling stop temperature T°C to 550°C or lower for 50 seconds or more, and thereafter cooling the steel to room temperature.

7. A method for producing a high-strength hot-dip galvanized steel sheet having a tensile strength of 980 MPa or more and being excellent in formability and crashworthiness, the method comprising:

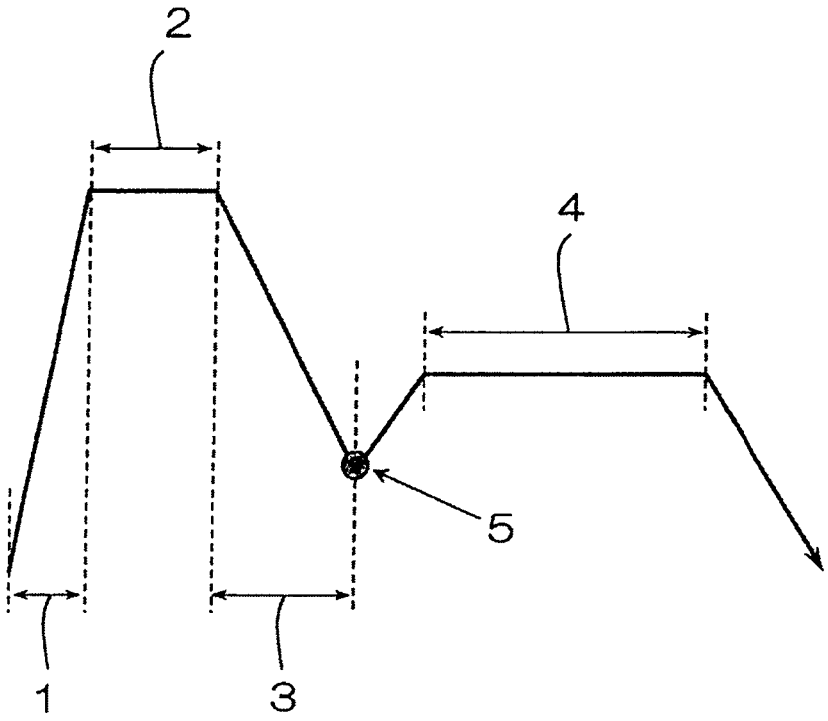
using a steel satisfying a component composition as set forth in claim 1 or 2,
hot rolling the steel with a rolling rate at a final stand of finish rolling being 5 to 25% and with a finish rolling end temperature being an Ar_3 point or higher to 900°C or lower, coiling the steel with a coiling temperature being 600°C or lower, and cooling the steel to room temperature,
cold rolling the steel,
heating the steel, at an average heating rate of 10°C/second or more, to a temperature region of an Ac_3 point or higher, and soaking the steel while holding the steel in the temperature region for 50 seconds or more,
cooling the steel at an average cooling rate of 10°C/second or more, to an arbitrary cooling stop temperature T°C that lies in a temperature range of 100°C or higher and an Ms point or lower, and
heating and holding the steel in a temperature region of higher than the cooling stop temperature T°C to 550°C or lower for 50 seconds or more, and after performing hot-dip galvanizing within a holding time, cooling the steel to room temperature.

8. A method for producing a high-strength hot-dip galvannealed steel sheet having a tensile strength of 980 MPa or more and being excellent in formability and crashworthiness, the method comprising:

using a steel satisfying a component composition as set forth in claim 1 or 2,
hot rolling the steel with a rolling rate at a final stand of finish rolling being 5 to 25% and with a finish rolling end temperature being an Ar_3 point or higher to 900°C or lower, coiling the steel with a coiling temperature being 600°C or lower, and cooling the steel to room temperature,
cold rolling the steel,
heating the steel, at an average heating rate of 10°C/second or more, to a temperature region of an Ac_3 point or higher, and soaking the steel while holding the steel in the temperature region for 50 seconds or more,
cooling the steel at an average cooling rate of 10°C/second or more, to an arbitrary cooling stop temperature T°C that lies in a temperature range of 100°C or higher and an Ms point or lower, and
heating and holding the steel in a temperature region of higher than the cooling stop temperature T°C to 550°C

or lower for 50 seconds or more, and after performing hot-dip galvanizing within a holding time, further performing an alloying treatment and thereafter cooling the steel to room temperature.

FIG. 1



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2016/056168

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/60(2006.01)i, *C21D8/02*(2006.01)i, *C21D9/46*(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, C21D8/02-8/04, C21D9/46-9/48

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	WO 2014/092025 A1 (Kobe Steel, Ltd.), 19 June 2014 (19.06.2014), claims; tables 1 to 7; fig. 2 & US 2015/0299834 A1 claims; tables 1 to 7; fig. 2 & CN 104838027 A & JP 2014-133944 A	1-8
A	WO 2009/099079 A1 (JFE Steel Corp.), 13 August 2009 (13.08.2009), claims; tables 1 to 5 & US 2011/0198002 A1 claims; tables 1 to 5 & EP 2267176 A1 & CN 101939456 A & JP 2009-209450 A	1-8

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

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Date of the actual completion of the international search	Date of mailing of the international search report
24 May 2016 (24.05.16)	07 June 2016 (07.06.16)

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

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2016/056168

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2010/029983 A1 (JFE Steel Corp.), 18 March 2010 (18.03.2010), claims; tables 1 to 7; fig. 1 & US 2011/0146852 A1 claims; tables 1 to 7; fig. 1 & EP 2325346 A1 & CN 102149840 A & JP 2010-90475 A	1-8
P,A	WO 2015/151427 A1 (JFE Steel Corp.), 08 October 2015 (08.10.2015), claims; paragraphs [0066] to [0070]; tables 1 to 3 (Family: none)	1-8

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REFERENCES CITED IN THE DESCRIPTION

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- **WILLIAM C. LESLIE.** The Physical Metallurgy of Steels. Maruzen Co., Ltd, 31 May 1985, 273 **[0057]**
- **P. LAROUR ; H. PAULI ; T. KURZ ; T. HEBESBERGER.** *Influence of post uniform tensile and bending properties on the crash behaviour of AHSS and press-hardening steel grades* **[0114]**