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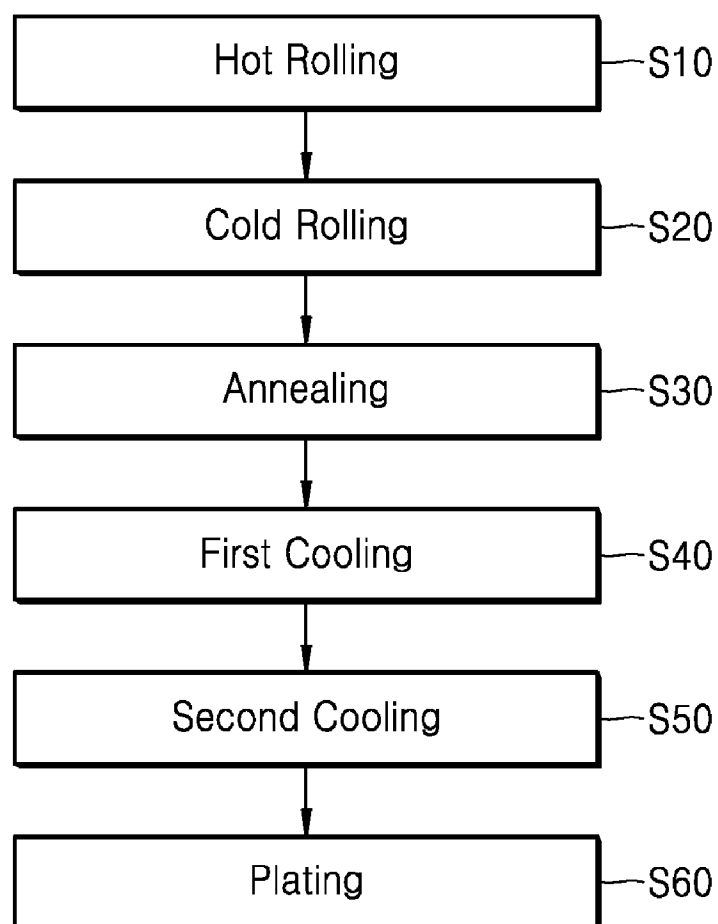
(54) **HIGH-STRENGTH COLD ROLLED STEEL SHEET AND MANUFACTURING METHOD THEREFOR**

(57) According to one embodiment of the present invention, provided is a high-strength cold-rolled steel sheet comprising, in wt%, carbon (C): 0.08% to 0.15%, silicon (Si): 0.8% to 1.5%, manganese (Mn): 2.0% to 3.0%, aluminum (Al): greater than 0% to 1.0%, phosphorus (P): greater than 0% and not greater than 0.02%, sulfur (S): greater than 0% and not greater than 0.01%, nitrogen (N): greater than 0% and not greater

than 0.01%, boron (B): 0.001% to 0.005%, a total of at least one selected from titanium (Ti) and niobium (Nb): not greater than 0.1% (excluding 0%), and the remainder being iron (Fe) and other unavoidable impurities, wherein the final microstructure consists of tempered martensite, bainite, fresh martensite, ferrite, and retained austenite.

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FIG. 1



Description

TECHNICAL FIELD

[0001] The technical concept of the present invention relates to a cold-rolled steel sheet, and more particularly, to a high-strength cold-rolled steel sheet having high strength together with excellent formability, and a method for manufacturing the same.

BACKGROUND ART

[0002] High-strength steel for automotive steel sheets is being developed in the direction of satisfying two factors: weight reduction of vehicles due to strengthened energy resource and environmental regulations, and securing collision stability due to strengthened safety regulations. Steel sheets used as vehicle body structural members require a tensile strength of 1 GPa class. In addition, a high yield ratio (YS/TS) is required to improve the collision performance of the vehicle body. To improve collision stability and formability in part manufacturing, it is necessary to develop materials with high yield strength and excellent ductility. In particular, high-strength steel sheets used for parts having complex shapes require materials with excellent characteristics such as elongation and hole expandability. However, since strength and elongation are in a trade-off relationship, as the material strength gradually increases, a problem arises in that forming of parts becomes difficult, and various studies are being conducted for the development of high-strength steel with excellent formability.

[0003] For example, there is Dual Phase (DP) steel in which massive soft ferrite and hard martensite are uniformly distributed in the microstructure to secure both strength and elongation. However, DP steel has a characteristic of having a low yield ratio (YS/TS) because mobile dislocations are introduced into ferrite during martensite transformation. Transformation-Induced Plasticity (TRIP) steel is a steel that utilizes the phenomenon of transformation into martensite during plastic deformation of retained austenite, and has the advantage of being able to utilize both the properties of austenite, which has excellent formability, and the properties of hard martensite after forming. TRIP steel has a high elongation, but is characterized by a low hole expandability value.

[0004] Therefore, there is a demand for a steel grade having a high yield ratio and excellent elongation as well as high hole expandability in an ultra-high-strength steel sheet with a strength of 1 GPa class or higher.

DETAILED DESCRIPTION OF THE INVENTION

TECHNICAL PROBLEM

[0005] A technical object to be achieved by the technical concept of the present invention is to provide an ultra-high-strength cold-rolled hot-dip galvanized steel sheet having excellent elongation and hole expandability, and a method for manufacturing the same.

[0006] However, such an object is illustrative, and the technical concept of the present invention is not limited thereto.

TECHNICAL SOLUTION

[0007] According to one aspect of the present invention, a high-strength cold-rolled steel sheet is provided.

[0008] According to one embodiment of the present invention, the cold-rolled steel sheet contains, in wt%, carbon (C): 0.08% to 0.15%, silicon (Si): 0.8% to 1.5%, manganese (Mn): 2.0% to 3.0%, aluminum (Al): greater than 0% to 1.0%, phosphorus (P): greater than 0% and not greater than 0.02%, sulfur (S): greater than 0% and not greater than 0.01%, nitrogen (N): greater than 0% and not greater than 0.01%, boron (B): 0.001% to 0.005%, a total of at least one selected from titanium (Ti) and niobium (Nb): not greater than 0.1% (excluding 0%), and the remainder being iron (Fe) and other unavoidable impurities, and the final microstructure may consist of tempered martensite, bainite, fresh martensite, ferrite, and retained austenite.

[0009] According to one embodiment, the high-strength cold-rolled steel sheet may satisfy Equation 1) and Equation 2) below.

$$\text{Equation 1): } 10 \times C + 0.4 \times (Si + 6 \times Al) - 0.4 \times Mn + 15 \times (Ti + Nb) - 52.5 \times B \leq 1.2$$

$$\text{Equation 2): } \text{Yield ratio (YR)} \times \text{Elongation (EL)} \times \text{Hole expansion ratio (HER)} \geq 400$$

(where the element symbols in Equation 1) represent the contents of the respective elements in wt%.)

[0010] According to one embodiment, the high-strength cold-rolled steel sheet may have, in area fraction, a combined fraction of the tempered martensite and bainite of 60 to 80%, a fraction of fresh martensite of less than 10%, a fraction of the ferrite of 10% to 30%, and a fraction of the retained austenite of 1 to 5%.

[0011] According to one embodiment, the ratio of the fresh martensite (FM) to the sum of the tempered martensite and bainite (TM+B) may be $FM/(TM+B) < 0.25$.

[0012] According to one embodiment, the high-strength cold-rolled steel sheet may further comprise, in wt%, at least one selected from molybdenum (Mo), chromium (Cr), copper (Cu), and nickel (Ni) in a total amount of not greater than 0.5% (excluding 0%).

[0013] According to one embodiment, the grain size of the tempered martensite and bainite may be 5 μm or less.

[0014] According to one embodiment, the cold-rolled steel sheet may have a tensile strength (TS) of 980 MPa or more, and a product of tensile strength (TS) and hole expansion ratio (HER) ($TS \times HER$) of 50,000 MPa% or more.

[0015] According to one embodiment, the titanium (Ti) may be contained in an amount of 0.015% or more and 0.04% or less, and the niobium (Nb) may be contained in an amount of 0.06% or more and 0.085% or less.

[0016] According to another aspect of the present invention, a method for manufacturing a high-strength cold-rolled steel sheet is provided.

[0017] According to one embodiment of the present invention, the method for manufacturing the high-strength cold-rolled steel sheet includes: (a) hot-rolling a steel material comprising, in wt%, C: 0.08% to 0.15%, Si: 0.8% to 1.5%, Mn: 2.0% to 3.0%, Al: greater than 0% to 1.0%, P: greater than 0% and not greater than 0.02%, S: greater than 0% and not greater than 0.01%, N: greater than 0% and not greater than 0.01%, B: 0.001% to 0.005%, a total of at least one selected from Ti and Nb: not greater than 0.1% (excluding 0%), and the remainder being Fe and other unavoidable impurities; (b) cold-rolling the hot-rolled steel material; (c) subjecting the cold-rolled steel material to annealing heat treatment; (d) cooling the annealed steel material to a temperature at or below the Ms temperature; and (e) plating the cooled steel material, wherein step (a) includes performing rolling with a reduction ratio per pass of 40% or more for at least one pass, and rolling such that the total reduction ratio of the 1st through 3rd passes is higher than the total reduction ratio of the remaining passes, and step (d) includes: a first cooling step of first-cooling at a first cooling rate to a first cooling end temperature in the range of 620°C to 720°C; and a second cooling step of second-cooling after the first cooling at a second cooling rate faster than the first cooling rate to a second cooling end temperature at or below the Ms temperature.

[0018] According to one embodiment, the steel material may satisfy Equation 1) below.

$$\text{Equation 1): } 10 \times C + 0.4 \times (Si + 6 \times Al) - 0.4 \times Mn + 15 \times (Ti + Nb) - 52.5 \times B \leq 1.2$$

(where the element symbols in Equation 1) represent the contents of the respective elements in wt%.)

[0019] According to one embodiment, in the method for manufacturing the cold-rolled steel sheet, the steel material may further comprise, in wt%, at least one selected from Mo, Cr, Cu, and Ni in a total amount of not greater than 0.5% (excluding 0%).

[0020] According to one embodiment, the second cooling end temperature may be a temperature of Ms - 140°C or more and Ms - 30°C or less.

[0021] According to one embodiment, the titanium (Ti) may be contained in an amount of 0.015% or more and 0.04% or less, and the niobium (Nb) may be contained in an amount of 0.06% or more and 0.085% or less.

[0022] According to one embodiment, the first cooling rate may have a range of 3°C/s to 20°C/s.

[0023] According to one embodiment, the second cooling rate may have a range of 15°C/s to 100°C/s.

[0024] According to one embodiment, step (a) may include: (a-1) reheating the steel material at 1150 to 1300°C; (a-2) hot-rolling the steel material under a condition where the finish rolling temperature is 850 to 950°C; and (a-3) coiling the steel material at 400 to 600°C.

[0025] According to one embodiment, after step (a-2) and before step (a-3), a step of cooling to 680°C or less at a cooling rate of 80°C/s or more may be performed.

ADVANTAGEOUS EFFECTS

[0026] According to the technical concept of the present invention, a steel sheet having high strength and excellent ductility can be manufactured, and thus it can be suitably applied as a material for automotive structural members and the like. In addition, a cold-rolled steel sheet having a higher yield ratio compared to conventional DP steel, thereby having excellent hole expandability, excellent collision resistance, and excellent formability, can be manufactured. The above-described advantageous effects of the present invention are described by way of example, and the scope of the present invention is not limited by these effects.

BRIEF DESCRIPTION OF DRAWINGS

[0027]

FIG. 1 is a flowchart schematically showing a method for manufacturing a cold-rolled steel sheet according to an embodiment of the present invention, and FIG. 2 is a diagram showing an outline of heat treatment including annealing, cooling, and plating processes in a method for manufacturing a cold-rolled steel sheet according to an embodiment of the present invention.

FIG. 3 is a graph showing the properties of cold-rolled steel sheets according to the experimental example of the present invention.

MODE OF THE INVENTION

Hereinafter, preferred embodiments of the present invention will be described in detail with reference to the accompanying drawings. The embodiments of the present invention are provided to more completely explain the technical concept of the present invention to those skilled in the art, and the following embodiments may be modified into various other forms, and the scope of the technical concept of the present invention is not limited to the following embodiments. Rather, these embodiments are provided so that this disclosure will be thorough and complete and will fully convey the technical concept of the present invention to those skilled in the art. Throughout this specification, the same reference numerals denote the same elements throughout. Furthermore, various elements and regions in the drawings are schematically drawn. Therefore, the technical concept of the present invention is not limited by the relative sizes or intervals shown in the accompanying drawings.

[0029] In the present specification and claims, the phase fraction refers to the area ratio (area%) derived by analyzing microstructure photographs using an image analyzer. In addition, the content or concentration of a specific component means weight% unless otherwise specified.

[0030] The technical concept of the present invention is to provide a cold-rolled high-strength steel sheet having a tensile strength (TS) of 980 MPa or more, a yield ratio (YR) $\times$ elongation (EL) $\times$ hole expansion ratio (HER) $\geq$ 400, which has very excellent formability, and a method for manufacturing such a cold-rolled steel sheet.

[0031] In addition, according to an embodiment of the present invention, a cold-rolled steel sheet in which the product of tensile strength (TS) and hole expansion ratio (HER) (TS $\times$ HER) is 50,000 MPa% or more can be provided.

[0032] Hereinafter, the amount of alloy and the heat treatment conditions suitable therefor for securing the target tensile strength, elongation, yield ratio, and hole expandability in the present invention will be described.

[0033] First, the high-strength cold-rolled steel sheet according to the technical concept of the present invention will be described in detail.

[0034] The high-strength cold-rolled steel sheet according to one embodiment of the present invention contains, in wt%, carbon (C): 0.08% to 0.15%, silicon (Si): 0.8% to 1.5%, manganese (Mn): 2.0% to 3.0%, aluminum (Al): greater than 0% to 1.0%, phosphorus (P): greater than 0% and not greater than 0.02%, sulfur (S): greater than 0% and not greater than 0.01%, nitrogen (N): greater than 0% and not greater than 0.01%, boron (B): 0.001% to 0.005%, a total of at least one selected from titanium (Ti) and niobium (Nb): not greater than 0.1% (excluding 0%), and the remainder being iron (Fe) and other unavoidable impurities. Optionally, at least one selected from molybdenum (Mo), chromium (Cr), copper (Cu), and nickel (Ni) may be further included in a total amount of not greater than 0.5% (excluding 0%).

[0035] Hereinafter, the role and content of each component included in the high-strength cold-rolled steel sheet according to the present invention will be described. In this case, the contents of the component elements all mean weight% based on the entire steel sheet.

Carbon (C): 0.08% to 0.15%

[0036] Carbon is added to secure an appropriate fraction and stability of retained austenite. The carbon content has a range of 0.08% to 0.15% by weight. If the carbon content is less than 0.08%, the fraction of retained austenite in the final microstructure is insufficient, making it difficult to obtain the target ductility, and fresh martensite is difficult to form. On the other hand, if it exceeds 0.15%, the strength increases excessively, and carbides are likely to be generated, which may be disadvantageous for weldability.

Silicon (Si): 0.8% to 1.5%

[0037] Silicon is a ferrite-stabilizing element that retards the formation of carbides in ferrite and has a solid solution strengthening effect. The silicon content has a range of 0.8% to 1.5% by weight. If the silicon content is less than 0.8%, it is difficult to exhibit the above-described effects, while if it exceeds 1.5%, oxides such as Mn_2SiO_4 may be

formed during manufacturing, impairing platability, and the carbon equivalent may increase, thereby reducing weldability.

Manganese (Mn): 2.0% to 3.0%

[0038] Manganese has a solid solution strengthening effect and contributes to strength improvement by increasing hardenability. The manganese content has a range of 2.0% to 3.0% by weight. If the manganese content is less than 2.0%, the effect is insufficient, making it difficult to secure strength. If it exceeds 3.0%, workability may decrease due to formation of inclusions such as MnS or segregation, delayed fracture resistance may decrease, and the carbon equivalent may increase, thereby reducing weldability.

Aluminum (Al): greater than 0% to 1.0%

[0039] Aluminum is used as a deoxidizing agent and may help to purify ferrite. Aluminum has a range of greater than 0% to 1.0% by weight. If aluminum is not contained, the deoxidizing effect is insufficient, while if it exceeds 1.0%, AlN may be formed during slab production in the continuous casting stage, which may cause cracks during continuous casting or hot rolling.

Phosphorus (P): greater than 0% and not greater than 0.02%

[0040] Phosphorus is an impurity contained in the steel manufacturing process, and although it can help to improve strength through solid solution strengthening, if it is contained in large amounts, low-temperature brittleness may occur. Therefore, the phosphorus content is preferably limited to 0.02% or less by weight.

Sulfur (S): greater than 0% and not greater than 0.01%

[0041] Sulfur is an impurity contained in the steel manufacturing process, and may form non-metallic inclusions such as FeS and MnS, thereby reducing toughness and weldability. Therefore, the sulfur content is preferably limited to 0.01% or less by weight.

Nitrogen (N): greater than 0% and not greater than 0.01%

[0042] Nitrogen is an element inevitably contained during steel production, and if it exceeds 0.01%, elongation may decrease due to delayed recrystallization, so it is preferable to reduce it as much as possible. Therefore, the nitrogen content is preferably limited to greater than 0% to 0.01% of the total weight of the steel sheet.

Boron (B): 0.001% to 0.005%

[0043] Boron is a hardenability element that suppresses the formation of polygonal ferrite and facilitates the formation of fresh martensite. Boron has a range of 0.001% to 0.005% by weight. If the boron content is less than 0.001%, the effect is insignificant, while if it exceeds 0.005%, workability decreases.

Total of at least one selected from titanium (Ti) and niobium (Nb): not greater than 0.1% (excluding 0%)

[0044] Titanium and niobium are strong carbonitride-forming elements that form fine precipitates with carbon and nitrogen present in the steel during hot rolling, thereby suppressing grain growth and improving strength. The total content of titanium and niobium has a range of not greater than 0.1% by weight. If neither titanium nor niobium is contained in the steel, it is difficult to exhibit a precipitation strengthening effect, while if it exceeds 0.1%, the strength becomes excessively high and ductility decreases.

[0045] In this case, when titanium is added, the titanium content is preferably added at 0.015% to 0.04%. In order to sufficiently obtain the effect of the boron described above, if boron combines with nitrogen in the steel to be lost as BN, the effect of boron cannot be obtained. Therefore, it is preferable to induce precipitation of TiN by adding titanium in a certain amount or more. However, if the titanium content exceeds 0.04%, defects such as nozzle clogging may occur due to the formation of coarse TiN, which may reduce continuous castability.

[0046] The remaining component of the high-strength cold-rolled steel sheet is iron (Fe). However, in the conventional steelmaking process, unintended impurities may inevitably be mixed in from raw materials or the surrounding environment, so they cannot be excluded. Since these impurities are known to anyone skilled in the art of the conventional manufacturing process, they are not specifically mentioned in the present specification.

[0047] Meanwhile, the high-strength cold-rolled steel sheet may selectively further comprise, in wt%, at least one selected from molybdenum (Mo), chromium (Cr), copper (Cu), and nickel (Ni) in a total amount of not greater than 0.5% (excluding 0%).

- 5 Total of at least one selected from molybdenum (Mo), chromium (Cr), copper (Cu), and nickel (Ni): not greater than 0.5% (excluding 0%)

[0048] Molybdenum increases hardenability and suppresses the generation of pearlite. It also refines martensite. Meanwhile, when molybdenum segregates at grain boundaries, ferrite grain growth stops, so the ferrite fraction decreases. To suppress this, when molybdenum is contained, it is limited to 0.50% or less.

[0049] Chromium, similarly to manganese, has a solid solution strengthening effect and contributes to strength improvement by increasing hardenability. If the chromium content exceeds 0.5%, the hardenability becomes excessive, the fraction of retained austenite decreases, the fraction of martensite increases, and ductility decreases.

[0050] Copper is an element effective for securing corrosion resistance, and enables blocking of the corrosive environment through surface concentration. If copper is added in excess of 0.5%, the corrosion rate of the corrosion-resistant steel sheet may increase.

[0051] Nickel, when added together with copper in the steel sheet, has the effect of increasing corrosion resistance. When nickel is added in an amount of 0.5% or less, the density of the Cu-concentrated layer in the steel sheet increases, which has the effect of increasing corrosion resistance.

[0052] The steel sheet according to the present invention having the alloy composition as described above may have a carbon equivalent defined as $10 \times C + 0.4 \times (Si + 6 \times Al) - 0.4 \times Mn + 15 \times (Ti + Nb) - 52.5 \times B$ (where C, Si, Al, Mn, Ti, Nb, and B are the weight ratios of carbon, silicon, aluminum, manganese, titanium, niobium, and boron, respectively) of 1.2 or less.

25 Microstructure of the Steel Sheet

[0053] The microstructure of the high-strength cold-rolled steel sheet according to the technical concept of the present invention may include tempered martensite, bainite, fresh martensite, ferrite, and retained austenite. In this case, in area fraction, the combined fraction of tempered martensite and bainite may be 60 to 80%, the fraction of fresh martensite may be less than 10%, the fraction of ferrite may be 10% to 30%, and the fraction of retained austenite may be 1 to 5%.

[0054] The area fraction refers to the area ratio derived by analyzing microstructure photographs obtained by Electron Backscatter Diffraction (EBSD) using an image analyzer. EBSD specimens can be prepared by polishing the cold-rolled steel sheet and removing surface defects. The area fraction can be derived by calculating the fraction of the image area through FE-SEM from images acquired by EBSD.

[0055] Since the hardness of tempered martensite and bainite is higher than that of ferrite and lower than that of fresh martensite, when the combined fraction of tempered martensite and bainite is secured at 60 to 80%, voids between the hard phase and the soft phase are less likely to occur.

[0056] Fresh martensite is a hard phase, and since it is difficult to deform during shearing, the occurrence of defects in press-worked products can be suppressed. However, if the area fraction of fresh martensite is 10% or more, voids are likely to occur during processing, and workability decreases. For this reason, the area fraction of fresh martensite is set to less than 10%.

[0057] Ferrite is a soft phase, and it is effective to constitute the metallic microstructure with ferrite grains having excellent ductility with low dislocation density. To obtain such an effect, the area fraction is set to 10% or more. On the other hand, if the area fraction exceeds 30%, since ferrite tends to deform, defects may occur during press forming. For this reason, the area fraction of ferrite is set to 10 to 30%.

[0058] The retained austenite phase transforms into martensite during processing such as punching, which is highly likely to deteriorate hole expandability. Therefore, the retained austenite phase is preferably controlled to 5% or less. Also, it is preferably 1% or more.

[0059] Furthermore, the grain size of tempered martensite and bainite may be 5 μm or less. In this case, the grain size is measured using EBSD as the circle-equivalent diameter of the region surrounded by boundaries having a misorientation of 10 degrees or more.

[0060] The ratio $FM/(TM+B)$ of the fresh martensite (FM) to the sum of the tempered martensite and bainite (TM+B) is set to less than 0.25. When the $FM/(TM+B)$ value is 0.25 or more, voids between the hard phase and the soft phase are easily generated during processing of the cold-rolled steel sheet, and workability may decrease.

[0061] The high-strength cold-rolled steel sheet of the present invention can be realized as a cold-rolled high-strength steel sheet with very excellent formability having a tensile strength (TS) of 980 MPa or more, a yield ratio $(YR) \times \text{elongation (EL)} \times \text{hole expansion ratio (HER)} \geq 400$.

[0062] In addition, the cold-rolled steel sheet may preferably have a product of tensile strength (TS) and hole expansion ratio (HER) ($TS \times HER$) of 50,000 MPa% or more.

[0063] Hereinafter, with reference to the accompanying drawings, a method for manufacturing a high-strength cold-rolled steel sheet having the above-described composition range according to the technical spirit of the present invention will be described.

Method for Manufacturing Cold-Rolled Steel Sheet

[0064] In the manufacturing method according to the present invention, the semi-finished product subject to the hot rolling process may be, for example, a slab. A slab in a semi-finished state can be obtained through a continuous casting process after obtaining molten steel of a predetermined composition through a steelmaking process.

[0065] FIG. 1 is a flowchart showing the method for manufacturing a high-strength cold-rolled steel sheet according to an embodiment of the present invention step by step.

[0066] The method for manufacturing a high-strength cold-rolled steel sheet according to an embodiment of the present invention includes: a step (S10) of hot-rolling the steel material having the above composition; a step (S20) of cold-rolling the hot-rolled steel material; a step (S30) of subjecting the cold-rolled steel material to annealing heat treatment; a step (S40) of first-cooling the annealed steel material; a step (S50) of second-cooling the steel material; and a step (S60) of plating the cooled steel material.

Hot Rolling Step

[0067] The steel slab having the alloy composition described above is reheated to a temperature of 1150 to 1300°C. The slab is manufactured in the form of a semi-finished product by continuously casting molten steel obtained through a steelmaking process, and is homogenized through the reheating process to eliminate component segregation occurring in the casting process, and is brought into a state where hot rolling can be performed. If the slab reheating temperature (SRT) is less than 1150°C, there is a problem that segregation of the slab is not sufficiently re-dissolved, and if it exceeds 1300°C, the size of austenite grains increases and process costs may increase. Reheating of the slab may be performed for 1 to 2 hours. If the reheating time is less than 1 hour, the reduction of segregation is not sufficient, and if it exceeds 2 hours, the grain size increases and process costs may increase.

[0068] After the reheating, hot rolling including rough rolling and finish rolling is performed, and for example, finish hot rolling can be performed at a finish delivery temperature (FDT) in the range of 850°C to 950°C to produce a hot-rolled steel sheet. If the finish rolling temperature is lower than 850°C, the rolling load increases sharply, reducing productivity, and if it exceeds 950°C, the grain size increases and strength may decrease.

[0069] The rough rolling temperature is preferably set to be at or above the temperature (T_{nr}) at which recrystallization of austenite stops, and can be performed, for example, at 1000°C to 1150°C. When rough rolling is performed for 2 or more passes, the reduction ratio of the last pass is preferably 40% or more. Here, the reduction ratio (%) refers to $\{[\text{thickness of material before rolling} - \text{thickness of material after rolling}] / \text{thickness of material before rolling}\} \times 100$.

[0070] During rough rolling, the microstructure recrystallized by the initial rolling undergoes grain growth due to the high temperature, but when the last pass is performed, as grain growth is delayed, the reduction ratio of the last pass greatly influences the grain size of the final microstructure. In addition, if the pass reduction ratio of rough rolling decreases, insufficient deformation may be transmitted to the central portion, causing deterioration in toughness due to coarsening of the central portion. Therefore, it is preferable to set the reduction ratio of the last pass to 40% or more for the purpose of austenite grain refinement and reduction of manganese segregation.

[0071] Finish rolling is performed for 5 to 7 passes on the rough-rolled steel material. In performing the finish rolling, the reduction ratio of the first pass is set to 40% or more, and the total reduction ratio of the 1st through 3rd passes is set to be higher than the total reduction ratio of the remaining passes. This is for the purpose of refining austenite grains and reducing manganese segregation. If the total reduction ratio of the initial 1st through 3rd passes is lower than the total reduction ratio of the remaining passes, coarse austenite grains are formed, making it impossible to obtain the desired microstructure, and it is difficult to secure strength and a uniform microstructure.

[0072] After hot rolling, the steel is cooled to 400 to 600°C and then coiled. If the coiling temperature is less than 400°C, the strength increases and the rolling load during cold rolling increases, and if it exceeds 600°C, ferrite and pearlite microstructures are excessively generated, which may deteriorate hole expandability, and defects may occur in subsequent processes due to surface oxidation and the like.

[0073] In the cooling process after hot rolling, cooling (rapid cooling) is performed at a high cooling rate of 80°C/s or more from the finish rolling end temperature to, for example, a temperature of 680°C, and thereafter, cooling (slow cooling) is performed at a low cooling rate of 5°C/s or more to a coiling temperature of 600°C or less.

[0074] The rapid cooling step is to prevent excessive ferrite transformation. In addition, since pearlite may be generated at a temperature of 680°C or higher, and microstructural nonuniformity may occur in subsequent processes,

thereby deteriorating hole expandability, the rapid cooling step is preferably applied up to a temperature of 680°C.

Cold Rolling Step

[0075] The hot-rolled steel sheet is subjected to pickling treatment for cleaning with an acid to remove the surface scale layer. Subsequently, the hot-rolled steel sheet is cold-rolled at, for example, an average reduction ratio of 30% to 80% to form a cold-rolled steel sheet. The higher the average reduction ratio, the more effective it is in improving formability due to microstructural refinement. If the average reduction ratio is less than 30%, it is difficult to obtain a uniform microstructure. If the average reduction ratio exceeds 80%, the roll force increases, increasing the process load. The microstructure of the cold-rolled steel sheet may have a structure in which the microstructure of the hot-rolled steel sheet is elongated.

[0076] After cold rolling is completed, the cold-rolled steel sheet undergoes annealing heat treatment and plating processes.

[0077] FIG. 2 is a diagram showing an outline of heat treatment including annealing, cooling, and plating processes in the method for manufacturing a cold-rolled steel sheet according to one embodiment of the present invention.

[0078] Hereinafter, the heat treatment after cold rolling will be described step by step with reference to FIG. 2.

Annealing Heat Treatment Step

[0079] S11 to S12 in FIG. 2 represent the annealing heat treatment step.

[0080] Referring to FIG. 2, the cold-rolled steel sheet is heated from room temperature to 800°C to 900°C (S11). The heating step (S11) is a step of nucleating austenite from martensite as the initial microstructure to determine the shape of the microstructure. The heating rate is preferably 2°C/s or more in consideration of productivity.

[0081] Subsequently, the steel sheet is subjected to first soaking at a temperature of 800°C to 900°C (S12). During annealing, the low-temperature phase undergoes reverse transformation to ferrite/austenite, and redistribution of carbon (C) and manganese (Mn) into austenite occurs. For sufficient reverse transformation and alloy element redistribution, a longer annealing time is preferable, but if the annealing time becomes excessively long, productivity may decrease. Therefore, the annealing holding time is limited to within 30 to 180 seconds.

[0082] Thereafter, the annealed steel sheet is first-cooled (S13) and second-cooled (S14). The first cooling region (S13) can be classified as a slow cooling section (SCS), and the second cooling region (S14) can be classified as a rapid cooling section (RCS).

[0083] In cooling the annealed steel sheet, a slow cooling section may be included depending on the heat treatment equipment. When a slow cooling section is included, the slow cooling end temperature should be 620°C to 720°C to control the ferrite phase fraction, and the cooling rate may have a range of 3°C/s to 20°C/s. If the temperature and cooling rate are out of the above range, the ferrite fraction decreases and ductility decreases.

[0084] After performing the first cooling step (S13) of slow cooling, the second cooling step (S14) of rapid cooling is performed on the steel sheet. The cooling end temperature of the second cooling step (S14) may be $M_s - 140^\circ\text{C}$ to $M_s - 30^\circ\text{C}$. The cooling rate of the second cooling step (S14) may be set to be greater than the cooling rate of the first cooling step (S13), and for example, cooling at a rate of 15°C/s or more may be performed. If the cooling rate is less than 15°C/s during cooling, polygonal ferrite or pearlite is generated during cooling, causing inferior tensile properties of the final steel. Therefore, the cooling rate may have a range of, for example, 15°C/s to 100°C/s. The second cooling end temperature can effectively increase austenite stability.

[0085] In the present invention, M_s can be determined by Equation 3) below, for example, but may vary slightly depending on process conditions and the like.

$$\text{Equation 3): } M_s(^{\circ}\text{C}) = 539 - 423C - 30.4Mn - 12.1Cr - 17.7Ni - 7.5Mo$$

(where the element symbols in Equation 3) represent the contents of the respective elements in wt%.)

[0086] If the cooling end temperature of the second cooling step (S14) exceeds $M_s - 30^\circ\text{C}$, alloy element redistribution is insufficient and austenite stability cannot be sufficiently secured. The higher the cooling end temperature, the more ferrite transformation occurs, which reduces strength and elongation.

[0087] After reaching the second cooling end temperature, second soaking of maintaining within a range of $\pm 20^\circ\text{C}$ for 10 to 100 seconds is performed (S15). At the initial stage of holding after rapid cooling, temperature homogenization of the steel proceeds, and during isothermal holding, a part of the retained austenite may transform into lower bainite or the like.

[0088] Subsequently, after reheating to a temperature of 350 to 550°C, the steel sheet is held in that temperature range for 30 to 500 seconds (S16).

[0089] Thereafter, the steel material is immersed in a hot-dip galvanizing bath to perform hot-dip galvanizing (GI) (S17-1). The temperature of the hot-dip galvanizing bath may be in the range of 400 to 600°C. If necessary, the steel material immersed in the plating bath is subjected to alloying heat treatment (GA) at, for example, a temperature range of 500 to 570°C (S17-2). After this process, final cooling is performed to 100°C or less at a cooling rate of 10°C/s or more.

[0090] In this case, the plating (S17-1) and alloying heat treatment (S17-2) times may also be included in the reheating holding time.

[0091] If necessary, it is also possible to perform temper rolling. The elongation during temper rolling is performed in the range of 0.1% to 1.0%.

[0092] The final microstructure of the cold-rolled steel sheet realized by the above-described manufacturing method may include tempered martensite, bainite, fresh martensite, ferrite, and retained austenite. In this case, in area fraction, the combined fraction of tempered martensite and bainite may be 60 to 80%, the fraction of fresh martensite may be less than 10%, the fraction of ferrite may be 10% to 30%, and the fraction of retained austenite may be 1 to 5%.

[0093] Furthermore, the ratio FM/(TM+B) of the fresh martensite (FM) to the sum of the tempered martensite and bainite (TM+B) may be less than 0.25. When the FM/(TM+B) value is 0.25 or more, voids between the hard phase and the soft phase are easily generated during processing of the cold-rolled steel sheet, and workability may decrease.

[0094] Within the component system range described in the present invention, the steel grade composed of the microstructure as described above obtained from the heat treatment process described above can be realized as a cold-rolled high-strength steel sheet with very excellent formability having a tensile strength (TS) of 980 MPa or more, a yield ratio (YR) $\times$ elongation (EL) $\times$ hole expansion ratio (HER) $\geq$ 400.

[0095] In addition, the cold-rolled steel sheet may preferably have a product of tensile strength (TS) and hole expansion ratio (HER) (TS $\times$ HER) of 50,000 MPa% or more.

Experimental Examples

[0096] Hereinafter, preferred experimental examples are presented to help the understanding of the present invention. However, the following experimental examples are only for the purpose of assisting the understanding of the present invention, and the present invention is not limited by the following experimental examples.

[0097] Regarding the analysis and measurement of this experimental example, the microstructure was analyzed using a scanning electron microscope (SEM), and XRD analysis was used to analyze the retained austenite fraction and the carbon content in retained austenite. Mechanical properties were evaluated by performing a tensile test according to KS No. 5 standard using a Zwick/Roell Corp Z100.

[0098] Steels having the compositions (unit: wt%) of Table 1 below were prepared, and cold-rolled steel sheets according to Examples and Comparative Examples were prepared through predetermined hot rolling, cold rolling, and heat treatment processes. The remainder is iron (Fe). In the Steel Grade column, Inv. 1 to Inv. 6 denote Inventive Steel 1 to Inventive Steel 6, and Comp. 1 to Comp. 9 denote Comparative Steel 1 to Comparative Steel 9.

[Table 1]

Steel Grade	C	Si	Mn	Al	P	S	Ti	Nb	Cr	Mo	B	Ms (°C)	Eq. 1
Inv. 1	0.10	0.9	2.5	0.03	0.010	0.002	0.020	-	0.3	-	0.0020	417	0.6
Inv. 2	0.12	1.3	2.7	0.03	0.012	0.002	0.020	-	-	-	0.0020	406	0.9
Inv. 3	0.12	0.9	2.5	0.03	0.010	0.002	0.020	-	-	-	0.0020	412	0.8
Inv. 4	0.12	0.8	2.4	0.025	0.012	0.002	0.015	0.02	0.2	0.4	0.0013	410	1.1
Inv. 5	0.11	0.8	2.6	0.025	0.012	0.002	0.015	0.02	0.5	0.2	0.0014	406	0.9
Inv. 6	0.12	0.8	2.4	0.025	0.012	0.002	0.015	0.02	0.5	0.2	0.0015	408	1.1
Comp. 1	0.13	0.9	2.5	0.03	0.012	0.002	0.020	0.025	0.3	-	0.0005	404	1.4
Comp. 2	0.16	0.9	2.5	0.03	0.010	0.002	0.020	0.025	-	-	0.0008	395	1.7
Comp. 3	0.14	0.6	2.3	0.047	0.012	0.002	0.040	0.02	0.2	0.2	0.0018	406	1.6
Comp. 4	0.12	0.6	2.3	0.5	0.012	0.002	0.010		0.8	0.1	0.0008	408	1.8
Comp. 5	0.13	0.6	2.3	0.054	0.012	0.002	0.040	0.02	0.2	0.06	0.0019	411	1.5
Comp. 6	0.14	0.6	2.2	0.5	0.012	0.002	0.015		0.8	0.1	0.0007	402	2.1

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(continued)

Steel Grade	C	Si	Mn	Al	P	S	Ti	Nb	Cr	Mo	B	Ms (°C)	Eq. 1
Comp. 7	0.10	0.5	2.4	0.5	0.012	0.002	0.015		0.8	0.1	0.0005	413	1.6
Comp. 8	0.14	0.6	2.6	0.04	0.012	0.002	0.030	0.02	0.2		0.0009	398	1.4
Comp. 9	0.14	0.6	2.4	0.04	0.012	0.002	0.020	0.02	0.2	0.1	0.0006	404	1.3

[0099] Table 2 shows the hot rolling process conditions for the steel grades in Table 1. In the Category column, Ex. 1 to Ex. 6 denote Example 1 to Example 6, and Comp. Ex 1 to Comp. Ex 11 denote Comparative Example 1 to Comparative Example 11.

[Table 2]

Steel Grade	Hot Rolling								Category	
	Heat Furnace	Rough Mill		Finish Mill				Coiling		
Slab Reheat Temp. (°C)	Rough Mill Exit Temp. (°C)	Rough Last Pass Reduction (%)	Finish Mill Exit Temp. (°C)	1st Pass Reduction (%)	1-3rd Pass Total Reduction (%)	Remaining Pass Total Reduction (%)	1st Coiling Rate (°C/s)	Coiling Temp. (°C)		
Inv. 1	1200	1090	45	925	44	119	101	133	560	Ex. 1
Inv. 2	1197	1060	46	920	45	120	100	97	570	Ex. 2
Inv. 3	1198	1045	46	915	45	122	98	128	550	Ex. 3
Inv. 4	1200	1078	45	905	46	123	97	93	540	Ex. 4
Inv. 5	1202	1082	45	908	45	118	102	126	570	Ex. 5
Inv. 6	1206	1064	46	911	46	119	101	86	570	Ex. 6
Comp. 1	1198	1062	45	907	46	120	100	102	550	Comp. Ex. 1
Comp. 2	1195	1059	46	906	45	120	100	115	550	Comp. Ex. 2
Comp. 3	1199	1080	45	904	45	121	99	116	550	Comp. Ex. 3
Comp. 4	1201	1090	46	912	46	125	95	123	550	Comp. Ex. 4
Comp. 5	1201	1063	45	909	45	119	101	121	550	Comp. Ex. 5
Comp. 6	1202	1078	44	908	45	122	98	119	550	Comp. Ex. 6
Comp. 7	1206	1085	45	903	44	121	99	134	560	Comp. Ex. 7
Comp. 8	1198	1071	46	905	46	120	100	128	550	Comp. Ex. 8
Comp. 9	1199	1080	46	904	45	119	101	126	550	Comp. Ex. 9
Inv. 2	1197	1060	46	907	35	105	115	134	570	Comp. Ex. 10
Inv. 3	1198	1045	46	903	45	121	99	133	550	Comp. Ex. 11

[0100] After hot-rolling the slabs of the above-mentioned steel grades under the conditions in Table 2, the surface scale was removed through pickling, and cold rolling was performed at a reduction ratio of 30 to 80%. Thereafter, the cold-rolled steel sheets were heat-treated under the conditions in Table 3.

[Table 3]

Steel Grade	Heat treatment										Category
	1st Soaking		1st Cooling		2nd Cooling		2nd Soaking	Reheating		Plating	
	Temp.	Holding time	Temp.	Rate	Temp.	Rate	Holding time	Temp.	Holding time		
Inv. 1	840	80	680	15	280	35	35	450	55	GA	Ex. 1
Inv. 2	830	80	680	12	270	35	35	450	55	GA	Ex. 2
Inv. 3	840	80	680	15	280	35	35	450	55	GA	Ex. 3
Inv. 4	830	80	650	5	300	28	35	440	55	GA	Ex. 4
Inv. 5	815	80	650	5	350	23	35	460	55	GA	Ex. 5
Inv. 6	830	80	650	5	330	23	35	460	55	GA	Ex. 6
Comp. 1	840	80	680	15	250	39	35	450	55	GA	Comp. Ex. 1
Comp. 2	810	80	680	10	280	35	35	450	55	GA	Comp. Ex. 2
Comp. 3	830	80	660	5	320	25	35	480	55	GA	Comp. Ex. 3
Comp. 4	815	80	620	6	300	23	35	460	55	GA	Comp. Ex. 4
Comp. 5	810	80	650	5	450	15	35	480	55	GA	Comp. Ex. 5
Comp. 6	840	80	650	6	350	20	35	460	55	GA	Comp. Ex. 6
Comp. 7	850	80	650	6	450	15	35	460	55	GA	Comp. Ex. 7
Comp. 8	830	80	650	6	350	22	35	480	55	GA	Comp. Ex. 8
Comp. 9	850	80	670	6	350	23	35	460	55	GA	Comp. Ex. 9
Inv. 2	830	80	680	12	270	35	35	450	55	GA	Comp. Ex. 10
Inv. 3	840	80	680	15	400	25	35	450	55	GI	Comp. Ex. 11

[0101] Table 4 shows the microstructure and mechanical properties of the cold-rolled steel sheets finally manufactured after completing the processes according to Tables 2 and 3. In Table 4, microstructure TM+B means it consists of tempered martensite and bainite, F denotes ferrite, FM denotes fresh martensite, RA denotes retained austenite, and FM/(TM+B) denotes the ratio of fresh martensite (FM) to the sum of tempered martensite and bainite (TM+B).

[0102] In addition, yield strength (YS), tensile strength (TS), elongation (EL), and hole expansion ratio (HER) are shown, and $YR \times EL \times HER$ represents yield ratio (YR) $\times$ elongation (EL) $\times$ hole expansion ratio (HER).

[Table 4]

No	Microstructure					Mechanical Property					Category
	TM+B	F	FM	RA	FM/(TM+B)	YS	TS	EL	HER	YR×EL×-HER	
Inv. 1	76	14	8	2	0.11	890	990	12.0	62	669	Ex. 1
Inv. 2	75	13	9	3	0.12	788	997	12.6	53	528	Ex. 2
Inv. 3	72	18	9	1	0.13	873	980	10.5	57	533	Ex. 3
Inv. 4	72	15	8	5	0.11	958	1090	12.1	43	457	Ex. 4
Inv. 5	74	14	9	3	0.12	892	1103	12.7	50	514	Ex. 5
Inv. 6	75	14	9	2	0.12	872	1062	12.8	47	494	Ex. 6
Comp. 1	82	12	3	3	0.04	788	1030	12.7	37	359	Comp. Ex. 1
Comp. 2	58	21	18	3	0.31	612	974	14.7	32	296	Comp. Ex. 2
Comp. 3	81	8	9	2	0.11	863	1118	12.1	38	355	Comp. Ex. 3
Comp. 4	28	42	29	1	1.04	519	930	15.1	25	211	Comp. Ex. 4
Comp. 5	30	33	37	0	1.23	519	1040	12.5	22	137	Comp. Ex. 5
Comp. 6	27	38	33	2	1.22	517	1046	12.9	21	134	Comp. Ex. 6
Comp. 7	35	36	29	0	0.83	516	987	14.2	20	148	Comp. Ex. 7
Comp. 8	41	24	33	2	0.80	579	960	14.5	27	236	Comp. Ex. 8
Comp. 9	38	24	37	1	0.97	564	970	15.6	25	227	Comp. Ex. 9
Inv. 2	77	11	9	3	0.12	832	1025	13.1	37	393	Comp. Ex. 10
Inv. 3	54	18	24	4	0.44	612	907	14.1	31	295	Comp. Ex. 11

[0103] FIG. 3 is a graph showing the properties of cold-rolled steel sheets according to the experimental example of the present invention.

[0104] Referring to Tables 1 and FIG. 3, Inventive Steels 1 to 6 satisfy the range of Equation 1) that the present invention aims to achieve by satisfying the alloy compositions proposed in the present invention.

[0105] On the other hand, Comparative Steels 1 to 9 deviate from the range of Equation 1) that the present invention aims to achieve by failing to satisfy the alloy compositions proposed in the present invention.

[0106] In addition, referring to Tables 4 and FIG. 3, all of Comparative Steels 1 to 9 showed a yield ratio (YR) × elongation (EL) × hole expansion ratio (HER) of less than 400, and all of Inventive Steels 1 to 6 showed a yield ratio (YR) × elongation (EL) × hole expansion ratio (HER) of 400 or more.

[0107] Referring to Table 2, Comparative Example 10 deviates from the process conditions proposed in the present invention because the total reduction ratio of the 1st through 3rd passes during finish rolling is lower than the total reduction ratio of the remaining passes. Referring to Tables 1 and 3, Comparative Example 11 does not satisfy the second cooling end temperature range of Ms - 140°C to Ms - 30°C proposed in the present invention.

[0108] Referring to Table 4, when comparing Example 2 and Comparative Example 10 using the same Inventive Steel 2, Example 2 satisfied all of the mechanical properties to be achieved by the present invention, while Comparative Example 10 showed a yield ratio (YR) × elongation (EL) × hole expansion ratio (HER) of less than 400. This appears to be because Comparative Example 10 deviates from the reduction ratio proposed in the present invention, and thus the effect of austenite grain refinement is insignificant.

[0109] In addition, when comparing Example 3 and Comparative Example 11 using the same Inventive Steel 3, Example 3 satisfied all of the mechanical properties to be achieved by the present invention, while Comparative Example 11 did not satisfy the tensile strength (TS): 980 MPa or more to be achieved by the present invention and showed a yield ratio (YR) × elongation (EL) × hole expansion ratio (HER) of less than 400.

[0110] Furthermore, while Example 3 satisfies the area fractions of each microstructure component at the fractions targeted by the present invention, Comparative Example 11 did not satisfy the compositional requirements of the microstructure proposed by the present invention: tempered martensite and bainite total of 60 to 80%, fresh martensite of less than 10%, and FM/(TM+B) < 0.25.

[0111] This appears to be because in Comparative Example 11, the second cooling end temperature exceeded Ms - 30°C, causing ferrite transformation to occur, which reduced strength and elongation, and sufficient austenite stability

could not be secured, making it impossible to obtain the target microstructure.

[0112] Comparative Examples 5 and 7 had a second cooling end temperature that exceeded $M_s - 30^\circ\text{C}$, so austenite stability was not sufficiently secured, and the area fraction of retained austenite targeted by the present invention: 1 to 5% was not satisfied.

[0113] From this, it can be seen that when all of the alloy compositions and process conditions proposed in the present invention are satisfied, a steel sheet having high strength and excellent ductility can be manufactured, and a cold-rolled steel sheet having a high yield ratio, excellent hole expandability, excellent collision resistance, and excellent formability can be manufactured.

[0114] The technical concept of the present invention described above is not limited to the above-described embodiments and the accompanying drawings, and it will be apparent to those of ordinary skill in the technical field to which the technical concept of the present invention belongs that various substitutions, modifications, and changes may be made without departing from the scope of the technical concept of the present invention.

Claims

1. A high-strength cold-rolled steel sheet comprising, in wt%, carbon (C): 0.08% to 0.15%, silicon (Si): 0.8% to 1.5%, manganese (Mn): 2.0% to 3.0%, aluminum (Al): greater than 0% to 1.0%, phosphorus (P): greater than 0% and not greater than 0.02%, sulfur (S): greater than 0% and not greater than 0.01%, nitrogen (N): greater than 0% and not greater than 0.01%, boron (B): 0.001% to 0.005%, a total of at least one selected from titanium (Ti) and niobium (Nb): not greater than 0.1% (excluding 0%), and the remainder being iron (Fe) and other unavoidable impurities, wherein the final microstructure consists of tempered martensite, bainite, fresh martensite, ferrite, and retained austenite.

2. The high-strength cold-rolled steel sheet of claim 1, satisfying Equation 1) and Equation 2) below:

$$\text{Equation 1): } 10 \times C + 0.4 \times (\text{Si} + 6 \times \text{Al}) - 0.4 \times \text{Mn} + 15 \times (\text{Ti} + \text{Nb}) - 52.5 \times \text{B} \leq 1.2$$

$$\text{Equation 2): } \text{Yield ratio (YR)} \times \text{Elongation (EL)} \times \text{Hole expansion ratio (HER)} \geq 400$$

(where the element symbols in Equation 1) represent the contents of the respective elements in wt%.)

3. The high-strength cold-rolled steel sheet of claim 1, wherein in area fraction, the combined fraction of the tempered martensite and the bainite is 60 to 80%, the fresh martensite is less than 10%, the fraction of the ferrite is 10% to 30%, and the fraction of the retained austenite is 1 to 5%.

4. The high-strength cold-rolled steel sheet of claim 1, wherein the ratio of the fresh martensite (FM) to the sum of the tempered martensite and the bainite (TM+B) is $\text{FM}/(\text{TM}+\text{B}) < 0.25$.

5. The high-strength cold-rolled steel sheet of claim 1, further comprising, in wt%, at least one selected from molybdenum (Mo), chromium (Cr), copper (Cu), and nickel (Ni) in a total amount of not greater than 0.5% (excluding 0%).

6. The high-strength cold-rolled steel sheet of claim 1, wherein the grain size of the tempered martensite and the bainite is 5 μm or less.

7. The high-strength cold-rolled steel sheet of claim 1, wherein the tensile strength (TS) is 980 MPa or more, and the product of the tensile strength (TS) and the hole expansion ratio (HER) ($\text{TS} \times \text{HER}$) is 50,000 MPa% or more.

8. The high-strength cold-rolled steel sheet of claim 1, wherein the titanium (Ti) is contained in an amount of 0.015% or more and 0.04% or less, and the niobium (Nb) is contained in an amount of 0.06% or more and 0.085% or less.

9. A method for manufacturing a high-strength cold-rolled steel sheet, comprising:

(a) hot-rolling a steel material comprising, in wt%, C: 0.08% to 0.15%, Si: 0.8% to 1.5%, Mn: 2.0% to 3.0%, Al:

greater than 0% to 1.0%, P: greater than 0% and not greater than 0.02%, S: greater than 0% and not greater than 0.01%, N: greater than 0% and not greater than 0.01%, B: 0.001% to 0.005%, a total of at least one selected from Ti and Nb: not greater than 0.1% (excluding 0%), and the remainder being Fe and other unavoidable impurities;

(b) cold-rolling the hot-rolled steel material;

(c) subjecting the cold-rolled steel material to annealing heat treatment;

(d) cooling the annealed steel material to a temperature at or below the Ms temperature; and

(e) plating the cooled steel material,

wherein step (a) includes performing rolling with a reduction ratio per pass of 40% or more for at least one pass, and rolling such that the total reduction ratio of the 1st through 3rd passes is higher than the total reduction ratio of the remaining passes, and step (d) includes:

a first cooling step of first-cooling at a first cooling rate to a first cooling end temperature in the range of 620°C to 720°C; and

a second cooling step of second-cooling after the first cooling at a second cooling rate faster than the first cooling rate to a second cooling end temperature at or below the Ms temperature.

10. The method for manufacturing a high-strength cold-rolled steel sheet of claim 9, wherein the steel material satisfies Equation 1) below:

$$\text{Equation 1): } 10 \times C + 0.4 \times (Si + 6 \times Al) - 0.4 \times Mn + 15 \times (Ti + Nb) - 52.5 \times B \leq 1.2$$

(where the element symbols in Equation 1) represent the contents of the respective elements in wt%.)

11. The method for manufacturing a high-strength cold-rolled steel sheet of claim 9, further comprising, in wt%, at least one selected from Mo, Cr, Cu, and Ni in a total amount of not greater than 0.5% (excluding 0%).

12. The method for manufacturing a high-strength cold-rolled steel sheet of claim 9, wherein the second cooling end temperature is a temperature of Ms - 140°C or more and Ms - 30°C or less.

13. The method for manufacturing a high-strength cold-rolled steel sheet of claim 9, wherein the titanium (Ti) is contained in an amount of 0.015% or more and 0.04% or less, and the niobium (Nb) is contained in an amount of 0.06% or more and 0.085% or less.

14. The method for manufacturing a high-strength cold-rolled steel sheet of claim 9, wherein the first cooling rate has a range of 3°C/s to 20°C/s.

15. The method for manufacturing a high-strength cold-rolled steel sheet of claim 9, wherein the second cooling rate has a range of 15°C/s to 100°C/s.

16. The method for manufacturing a high-strength cold-rolled steel sheet of claim 9, wherein step (a) includes:

(a-1) reheating the steel material at 1150 to 1300°C;

(a-2) hot-rolling the steel material under a condition where the finish rolling temperature is 850 to 950°C; and

(a-3) coiling the steel material at 400 to 600°C.

17. The method for manufacturing a high-strength cold-rolled steel sheet of claim 16, wherein after step (a-2) and before step (a-3), a step of cooling to 680°C or less at a cooling rate of 80°C/s or more is performed.

18. The method for manufacturing a high-strength cold-rolled steel sheet of claim 9, wherein the Ms temperature is defined by Equation 3) below:

$$\text{Equation 3): } Ms(^{\circ}C) = 539 - 423C - 30.4Mn - 12.1Cr - 17.7Ni - 7.5Mo$$

(where the element symbols in Equation 3) represent the contents of the respective elements in wt%.)

FIG. 1

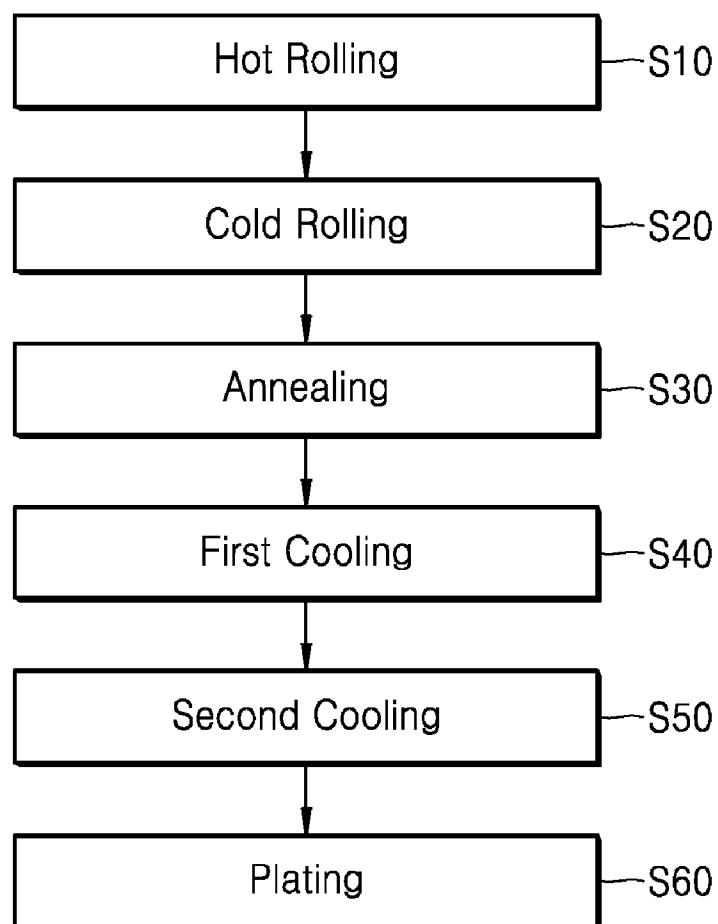


FIG. 2

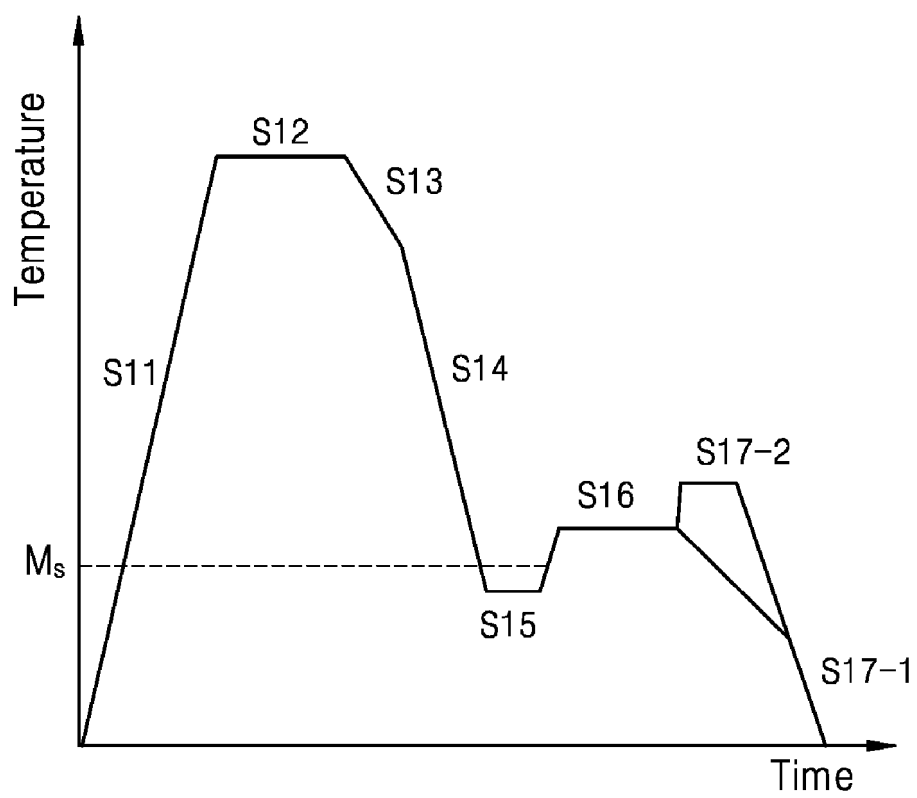
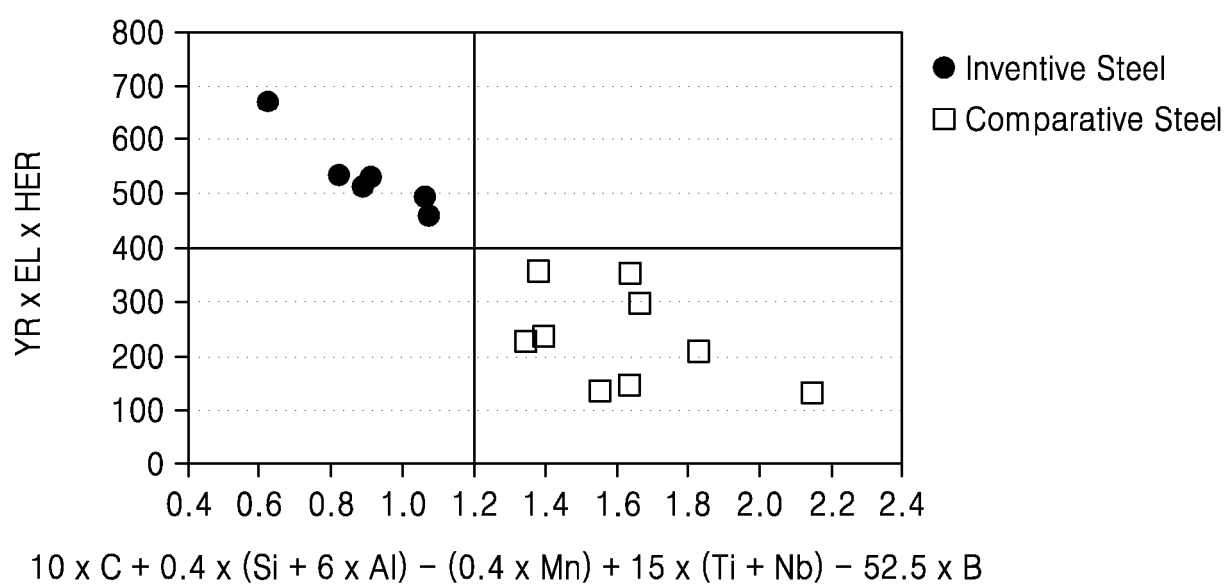


FIG. 3



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/017227

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/04(2006.01)i; C22C 38/02(2006.01)i; C22C 38/06(2006.01)i; C22C 38/00(2006.01)i; C22C 38/14(2006.01)i;
C22C 38/12(2006.01)i; C22C 38/58(2006.01)i; C21D 8/02(2006.01)i; C21D 9/46(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)

C22C 38/04(2006.01); B21B 3/00(2006.01); B22D 11/115(2006.01); C21D 9/46(2006.01); C22C 38/00(2006.01);
C22C 38/14(2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models: IPC as above

Japanese utility models and applications for utility models: IPC as above

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

eKOMPASS (KIPO internal) & keywords: 냉연강판(cold rolled steel sheet), 붕소(boron), 티타늄(titanium), 니오븀
(niobium), 템퍼드 마르텐사이트(tempered martensite), 베이나이트(bainite), 페라이트(ferrite), 소둔(annealing), 냉각
(cooling)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 10-2013-0140207 A (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORPORATION) 23 December 2013 (2013-12-23) See paragraphs [0097]-[0098], [0103], [0116], [0212], [0232], [0234] and [0259], claims 1-2 and 12-14 and tables 22-26.	1-18
A	KR 10-2021-0036967 A (JFE STEEL CORPORATION) 05 April 2021 (2021-04-05) See paragraphs [0163]-[0166] and claims 1-3.	1-18
A	KR 10-2018-0087347 A (JFE STEEL CORPORATION) 01 August 2018 (2018-08-01) See paragraphs [0098]-[0101] and claims 1 and 4-5.	1-18
A	JP 2023-539648 A (BAOSHAN IRON & STEEL CO., LTD.) 15 September 2023 (2023-09-15) See paragraph [0043] and claims 1-3.	1-18

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

* Special categories of cited documents:

“A” document defining the general state of the art which is not considered
to be of particular relevance

“D” document cited by the applicant in the international application

“E” earlier application or patent but published on or after the international
filing date

“L” document which may throw doubts on priority claim(s) or which is
cited to establish the publication date of another citation or other
special reason (as specified)

“O” document referring to an oral disclosure, use, exhibition or other
means

“P” document published prior to the international filing date but later than
the priority date claimed

“T” later document published after the international filing date or priority
date and not in conflict with the application but cited to understand the
principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be
considered novel or cannot be considered to involve an inventive step
when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be
considered to involve an inventive step when the document is
combined with one or more other such documents, such combination
being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search 24 February 2025	Date of mailing of the international search report 24 February 2025
Name and mailing address of the ISA/KR Korean Intellectual Property Office Government Complex-Daejeon Building 4, 189 Cheongsan- ro, Seo-gu, Daejeon 35208 Facsimile No. +82-42-481-8578	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/017227

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KR 10-2018-0120715 A (JFE STEEL CORPORATION) 06 November 2018 (2018-11-06) See claims 1-5.	1-18

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2024/017227

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