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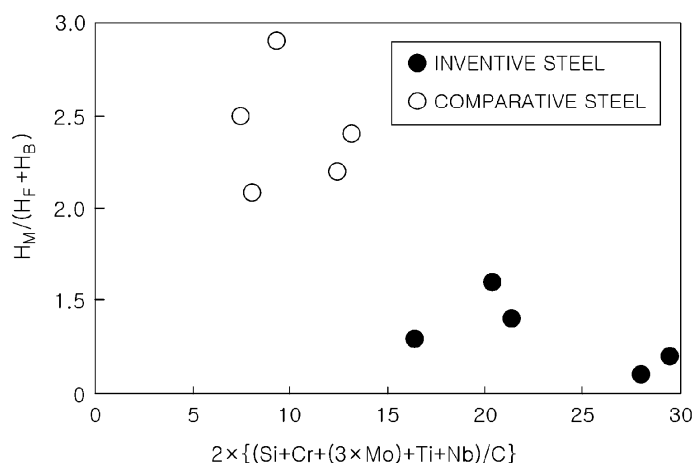
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(54) **STEEL SHEET AND METHOD FOR MANUFACTURING SAME**

(57) The present invention relates to a steel sheet suitable as a material for a vehicle structural member and the like, and, more specifically, to a high-strength

composite structure steel sheet with a tensile strength of 780 MPa or higher, and a method for manufacturing same.

[FIG. 1]



Description

Technical Field

[0001] The present disclosure relates to a steel sheet suitable as a material for a vehicle structural member and the like, and, more specifically, to a high-strength composite structure steel sheet with a tensile strength of 780 MPa or more, and a method for manufacturing the same.

Background Art

[0002] As fuel efficiency regulations for automobiles are being strengthened as part of efforts to preserve the global environment, the lightening of automobile bodies has been actively pursued. As one of the measures, weight reduction of automotive materials has been promoted by increasing the strength of steel sheets.

[0003] Generally, high-strength automotive materials are classified into precipitation-strengthened steels, bake-hardened steels, solid-solution-strengthened steels, and transformation strengthened steels. Among these, the transformation strengthened steels include dual phase steels (DP steels), complex phase steels (CP steels), and transformation induced plasticity steels (TRIP steels). Such transformation strengthened steels are also referred to as advanced high strength steels (AHSS).

[0004] Among the transformation strengthened steels, the dual phase (DP) steel is a type of steel that achieves high strength through a fine and uniform dispersion of hard martensite within a soft ferrite matrix. The complex phase (CP) steel has a microstructure including at least two phases selected from ferrite, martensite, and bainite, and further contains precipitation-hardening elements such as Ti and Nb to enhance strength. In addition, the transformation induced plasticity (TRIP) steel is a type of steel that achieves a combination of high strength and high ductility through transformation of finely and uniformly dispersed retained austenite into martensite during deformation at room temperature.

[0005] Recently, as automotive materials, there has been an increasing demand for more-strength steel sheets in order to improve fuel efficiency and durability of vehicle bodies. In addition, the high-strength steel sheets having a tensile strength of 780 MPa or more are increasingly used as structural or reinforcing members of vehicle bodies to ensure crash safety and protect passengers.

[0006] Until now, the development of steel sheets has primarily focused on improving stretch formability, mainly from the perspectives of ductility and tensile strength. However, as the strength level of automotive steel sheets has gradually increased, when such steel sheets are sheared using a shearing machine, cracking frequently occurs at the edge portion during processing, due to low ductility at a sheared surface, that is, a cut edge. In particular, for components such as sill side and seat parts that require stretch-flangeability, even when elongation is excellent, such components may not be used as a component if burring property (hole expansion ratio (HER)) is inferior.

[0007] Recently, to address the above issues, automakers that have traditionally employed DP steels with excellent formability for such components are currently demanding the development of DP steels that hold their inherent characteristics of low yield ratio and high ductility, while also exhibiting a high work-hardening rate and excellent burring property.

[0008] Meanwhile, automotive steel sheets are also required to have high corrosion resistance. Accordingly, hot-dip galvanized steel sheets having excellent corrosion resistance have conventionally been used as automotive materials. These hot-dip galvanized steel sheets may be manufactured using continuous hot-dip galvanizing equipment in which the recrystallization annealing process and the plating process are performed on the same line, thereby enabling low-cost manufacturing of corrosion-resistant steel sheets. In addition, the alloyed hot-dip galvanized steel sheets, which are manufactured by an alloying treatment involving reheating after hot-dip galvanizing, are widely used because they exhibit excellent corrosion resistance as well as good weldability and formability.

[0009] However, securing the surface quality of galvanized steel sheets is difficult due to Si and Mn, which are hardenability-enhancing and oxidizing elements added to achieve high strength of steel.

[0010] Therefore, for the lightening of automobiles, it is necessary to develop DP steels that hold their inherent characteristics of a low yield ratio and high ductility, while also exhibiting excellent burring property and stretch-flangeability. In addition, there is a demand for the development of hot-dip galvanized steel sheets having excellent corrosion resistance and weldability.

[0011] As the prior art, Patent Document 1, which relates to improving the formability of the high-strength steel sheets, discloses a composite structure steel sheet mainly comprised of martensite, and a manufacturing method for improving the formability of the steel sheet by dispersing fine copper precipitates having a particle size of 1 to 100 nm within the structure. In this patent document, Cu is added in an excessive amount of 2 to 5 wt% for forming fine Cu precipitates, which may cause hot shortness caused by Cu and also lead to a significant increase in production cost.

[0012] Patent Document 2 discloses a high-strength hot-dip galvanized steel sheet having an excellent hole expansion

sion ratio. Specifically, Patent Document 2 discloses a steel sheet having a microstructure in which ferrite serves as a matrix and pearlite is present in an amount of 2 to 10 area%, wherein strength is improved by precipitation strengthening and grain refinement through the addition of carbonitride-forming elements such as Nb, Ti, and V. However, the steel sheet according to this document exhibits a good hole expansion ratio; however, it has limitations in improving tensile strength, and there is a risk of cracking during press forming due to its high yield strength and low ductility.

[0013] Meanwhile, Patent Document 3 discloses a method for manufacturing a composite structure steel sheet with improved formability by utilizing a retained austenite phase. However, since the steel sheet according to this document contains relatively large amounts of Si and Al as alloying elements, it is difficult to ensure plating quality, and it is also difficult to secure surface quality during steelmaking and continuous casting. In addition, due to the relatively high amount of retained austenite, transformation-induced plasticity leads to a high initial yield strength YS, making it difficult to achieve a low yield ratio required for automobiles, and causing forming crack during press forming.

(Patent Document 1) Japanese Patent Laid-Open Publication No. 2005-264176

(Patent Document 2) Korean Patent Laid-Open Publication No. 10-2015-0073844

(Patent Document 3) Japanese Patent Laid-Open Publication No. 2015-113504

Summary of Invention

Technical Problem

[0014] An aspect of the present disclosure is to provide a steel sheet suitable for use as an automobile structural member, which has high strength of tensile strength of 780 MPa or more, along with excellent work hardening rate and hole expansion ratio (burring property). An aspect of the present disclosure is to provide a method for manufacturing the steel sheet.

[0015] Objects of the present disclosure are not limited to the above-mentioned objects. That is, other objects that are not mentioned may be obviously understood by those skilled in the art to which the present disclosure pertains from the following description.

Solution to Problem

[0016] According to an aspect of the present disclosure, a cold-rolled steel sheet includes: by wt%, carbon (C): 0.060 to 0.120%, silicon (Si): 1.20% or less (excluding 0%), manganese (Mn): 1.80 to 2.50%, molybdenum (Mo): 0.200% or less (excluding 0%), chromium (Cr): 0.800% or less (excluding 0%), phosphorus (P): 0.150% or less (excluding 0%), sulfur (S): 0.010% or less (excluding 0%), aluminum (sol.Al): 0.100% or less (excluding 0%), nitrogen (N): 0.010% or less (excluding 0%), and the balance being Fe and other unavoidable impurities.

[0017] In an example embodiment of the present disclosure, the cold-rolled steel sheet may satisfy Relational Equation 1 below.

[Relational Equation 1]

$$2 \times \{ (\text{Si} + \text{Cr} + (3 \times \text{Mo}) + \text{Ti} + \text{Nb}) / \text{C} \} \geq 15.0$$

(In Relational Equation 1, each element represents the weight content, and 0 is substituted when it is not added.)

[0018] In an example embodiment of the present disclosure, the cold-rolled steel sheet may have a microstructure including, in area fraction, 25 to 60% ferrite, 25 to 60% bainite, 20% or less martensite, and the balance being retained austenite.

[0019] In addition, in an example embodiment of the present disclosure, the number of fine martensite grains having an equivalent diameter of 3 μm or less may be 2.0×10^5 or more per unit area (1 mm^2).

[0020] The cold-rolled steel sheet having such an alloy composition system and microstructure may exhibit a low yield ratio and high ductility, while providing excellent work-hardening rate and burring properties.

[0021] In an example embodiment of the present disclosure, the cold-rolled steel sheet may further include one or more of titanium (Ti): 0.040% or less and niobium (Nb): 0.040% or less.

[0022] The cold-rolled steel sheet according to an example embodiment of the present disclosure may satisfy Relational Equation 2 below for the content of C, Si, Mo, and Cr in the ferrite. As a result, the hardness of the ferrite is increased, thereby reducing the hardness difference from a hard phase.

[Relational Equation 2]

$$2 \times \{ (Si_F + Cr_F + (3 \times Mo_F)) / C_F \} \geq 500$$

(In Relational Equation 2, each element represents the weight content contained within the ferrite.)

[0023] The cold-rolled steel sheet according to an example embodiment of the present disclosure may satisfy Relational Equation 3 below for an inter-phase hardness relationship of the microstructure, and the relationship among the work hardening rate (n), elongation (El), hole expansion ratio (HER), and yield ratio (YR) in a deformation range of 4 to 6% may satisfy Relational Equation 4 below.

[Relational Equation 3]

$$H_M / (H_F + H_B) \leq 2.0$$

(In Relational Equation 3, H_M represents the hardness value of martensite, H_F represents the hardness value of ferrite, and H_B represents the hardness value of bainite.)

[Relational Equation 4]

$$(n \times El \times HER) / YR \geq 150.0$$

(In Relational Equation 4, the units of each physical property are not considered.)

[0024] The cold-rolled steel sheet according to an example embodiment of the present disclosure may have a yield strength of 450 MPa or more, a tensile strength of 780 MPa or more, a yield ratio of 0.70 or less, and an elongation of 15% or more.

[0025] According to another aspect of the present disclosure, a method for manufacturing a cold-rolled steel sheet includes: preparing a steel slab; heating the steel slab to a temperature range of 1050 to 1300°C; obtaining a hot-rolled steel sheet by finishing hot-rolling the heated steel slab at a temperature of Ar3 transformation point or higher; coiling the hot-rolled steel sheet at a temperature range of 400 to 700°C; obtaining a cold-rolled steel sheet by cold-rolling the coiled hot-rolled steel sheet with a total reduction rate of 40 to 80%; continuously annealing the cold-rolled steel sheet in a temperature range of 780 to 835°C; primarily cooling the continuously annealed cold-rolled steel sheet to a temperature range of 630 to 690°C at a cooling rate of 1 to 14°C/s; secondarily cooling the primarily cooled cold-rolled steel sheet to a temperature range of 350 to 480°C at a cooling rate of 10°C/s or more; holding the secondarily cooled cold-rolled steel sheet for 100 seconds or more; and finally cooling the held cold-rolled steel sheet to a temperature of Ms-100°C or lower at a cooling rate of 3°C/s or higher.

[0026] In an example embodiment of the present disclosure, the steel slab may have the above-described alloy composition and satisfy Relational Equation 1.

[0027] In an example embodiment of the present disclosure, the method may further include obtaining a galvanized steel sheet by galvanizing the held cold-rolled steel sheet before final cooling.

[0028] In an example embodiment of the present disclosure, the method may further include selectively alloying heat-treating the galvanized steel sheet.

[0029] In an example embodiment of the present disclosure, the method may further include temper rolling the finally cooled cold-rolled steel sheet with a reduction rate of less than 1%.

Advantageous Effects of Invention

[0030] According to an aspect of the present disclosure, it is possible to provide a cold-rolled steel sheet (composite structure steel) that has a low yield ratio and high ductility, which are characteristics of DP steel, while simultaneously having excellent work-hardening rate and burring property.

[0031] According to an aspect of the present disclosure, the cold-rolled steel sheet is suitable for application as a material for automobiles, particularly for structural members.

Brief Description of Drawings

[0032]

FIG. 1 is a graph showing the relationship between Relational Equation 1 and mechanical properties (Relational Equation 3) according to an example embodiment of the present disclosure.

FIG. 2 is a graph showing the relationship between Relational Equation 1 and mechanical properties (Relational Equation 4) according to an example embodiment of the present disclosure.

Best Mode for Invention

[0033] The inventors of the present disclosure have conducted in-depth research on methods for improving a work-hardening rate along with a hole expansion ratio (burring property) while preserving a low yield ratio and high elongation of DP steel, which has been used as a material for conventional automotive structural components.

[0034] Through extensive studies, the inventors have found that, for steel sheets with a tensile strength of 780 MPa or more, by optimizing an alloy composition system and manufacturing conditions, particularly an annealing process, enables the formation of a microstructure that is advantageous for improving the work-hardening rate and burring property. As a result, the present disclosure is provided.

[0035] Hereinafter, the present disclosure will be described in detail.

[0036] A steel sheet according to an aspect of the present disclosure may include, by wt%, carbon (C): 0.060 to 0.120%, silicon (Si): 1.20% or less (excluding 0%), manganese (Mn): 1.80 to 2.50%, molybdenum (Mo): 0.200% or less (excluding 0%), chromium (Cr): 0.800% or less (excluding 0%), phosphorus (P): 0.150% or less (excluding 0%), sulfur (S): 0.010% or less (excluding 0%), aluminum (sol.Al): 0.100% or less (excluding 0%), and nitrogen (N): 0.010% or less (excluding 0%).

[0037] Hereinafter, the reasons for limiting an alloy composition of a steel sheet according to an example embodiment of the present disclosure will be described in detail below. Meanwhile, unless specifically mentioned otherwise, the content of each element is based on weight, and the ratio of the microstructure is based on area.

Carbon (C): 0.060 to 0.120%

[0038] Carbon (C) is a very important element added to strengthen a transformation structure, and contributes to strengthening of steel, while also being effective in promoting the formation of a martensite phase in steels having a composite structure.

[0039] As the C content increases, the amount of martensite formed in the steel increases. In an example embodiment of the present disclosure, when the C content exceeds 0.120%, strength is increased due to an increased amount of martensite formed; however, the strength difference between martensite and ferrite having a relatively low carbon concentration increases. Since this strength difference facilitates fracture at the phase interfaces under applied stress, the bending properties and stretch-flangeability of the steel are inferior. Additionally, weldability is inferior, leading to welding defects during part processing at the customer company. On the other hand, when the C content is less than 0.060%, it is very difficult to secure the desired strength.

[0040] Therefore, in an example embodiment of the present disclosure, C may be included in an amount of 0.060 to 0.120%. According to another example embodiment of the present disclosure, C may be 0.070% or more, or 0.080% or more. According to another example embodiment, C may be 0.150% or less, or 0.110% or less.

Silicon (Si): 1.20% or less (excluding 0%)

[0041] Silicon (Si) is a useful element that may secure strength without reducing the ductility of steel. Furthermore, the Si is effective in promoting the formation of ferrite and promoting the formation of martensite by encouraging the concentration of C into untransformed austenite. Additionally, due to its high solid solution strengthening ability, Si increases the strength of ferrite and is an effective element for reducing the hardness difference between phases.

[0042] In an example embodiment of the present disclosure, when the Si content exceeds 1.20%, the surface quality deteriorates during the plating process of steel, making it impossible to secure the surface quality of the plated steel sheet. In an example embodiment of the present disclosure, the lower limit of the Si content is not specifically limited; since the effect of Si may be obtained at a level added during the steel manufacturing process, it may be limited to greater than 0% in consideration of this.

[0043] Therefore, in an example embodiment of the present disclosure, the Si may be included in an amount greater than 0% to 1.20%. According to another example embodiment of the present disclosure, the Si may be 0.05% or more, or 0.11% or more. According to another example embodiment, the Si may be 1.10% or less, or 1.05% or less.

Manganese (Mn): 1.80 to 2.50%

[0044] Manganese (Mn) is an element advantageous for strengthening steel, which refines grains without impairing the ductility of the steel and completely precipitates sulfur (S) in the steel as MnS, thereby preventing hot brittleness caused by FeS formation. Furthermore, in composite structure steel, the Mn plays a role in lowering the critical cooling rate at which the martensite phase is formed, and thus contributes to the easier formation of the martensite phase.

[0045] In an example embodiment of the present disclosure, when the Mn content is less than 1.80%, the strengthening effect of the steel is insufficient, making it difficult to secure the target level of strength. On the other hand, when the Mn content exceeds 2.50%, problems are likely to occur in the weldability and hot rolling properties of the steel. In addition, excessive formation of the martensite phase leads to material instability, and the formation of Mn-Band (Mn oxide bands) in the structure increases the risk of processing cracks and sheet fracture. In addition, the Mn oxide leaches out onto the steel surface during the annealing process, significantly impairing plating performance during subsequent plating.

[0046] Accordingly, in an example embodiment of the present disclosure, the Mn may be included in an amount of 1.80 to 2.50%. According to another example embodiment of the present disclosure, the Mn may be included in an amount of 1.85% or more, or 1.90% or more. According to another example embodiment, the Mn may be 2.45% or less.

Molybdenum (Mo): 0.200% or less (excluding 0%)

[0047] Molybdenum (Mo) is an element useful for delaying the transformation of austenite into pearlite, while simultaneously refining ferrite and improving strength. This Mo has the advantage of enabling yield ratio control by increasing the hardenability of steel and forming fine martensite at grain boundaries. However, since it is an expensive element, increasing the Mo content leads to manufacturing disadvantages, and as a result, it is advantageous to appropriately control the Mo content.

[0048] In an example embodiment of the present disclosure, when the Mo content exceeds 0.200%, the alloy cost increases sharply, thereby deteriorating economic efficiency. In addition, the grains become excessively refined, and solid-solution strengthening becomes excessive, which leads to the deterioration in ductility of the steel. In an example embodiment of the present disclosure, the lower limit of the Mo content is not specifically limited; since the effect of Mo may be obtained at a level added during the steel manufacturing process, it may be limited to greater than 0% in consideration of this.

[0049] Therefore, in an example embodiment of the present disclosure, the Mo may be included in an amount greater than 0% to 0.200%. According to another example embodiment, the Mo may be 0.001% or more. According to another example embodiment, the Mo may be 0.180% or less, or 0.170% or less.

Chromium (Cr): 0.800% or less (excluding 0%)

[0050] Chromium (Cr) is an element having characteristics similar to the above-described Mn, and may be added to improve the hardenability of steel and secure high strength. The Cr is effective in forming martensite and is an element advantageous for manufacturing high-ductility composite structural steel by minimizing the decrease in elongation relative to the increase in strength. In particular, Cr-based carbides such as Cr_{23}C_6 are formed during the hot rolling process. During the annealing process, some of these carbides are dissolved while others remain undissolved, thereby enabling control of the amount of carbon in solid solution in martensite to an appropriate level or lower after subsequent cooling. As a result, the occurrence of yield point elongation (YP-EI) is suppressed, which is advantageous for manufacturing composite structural steel with a low yield ratio.

[0051] In an example embodiment of the present disclosure, when the Cr content exceeds 0.800%, the hardenability of the steel is improved, which is advantageous for martensite formation. However, excessive addition of Cr also increases the fractioning of Cr-based carbides, and these carbides become coarsened, resulting in coarsening of martensite after annealing and a decrease in elongation of the steel. In an example embodiment of the present disclosure, the lower limit of the Cr content is not specifically limited; since the effect of Cr may be obtained at a level added during the steel manufacturing process, it may be limited to greater than 0% in consideration of this.

[0052] Therefore, in an example embodiment of the present disclosure, the Cr may be included in an amount greater than 0% to 0.800%. According to another example embodiment of the present disclosure, the Cr may be 0.010% or more, or 0.011% or more. According to another example embodiment, the Cr may be 0.750% or less, or 0.700% or less.

Phosphorus (P): 0.150% or less (excluding 0%)

[0053] Phosphorus (P) is an element advantageous for securing strength without significantly impairing the formability of steel; however, when added in excess, the likelihood of brittle fracture increases significantly, thereby increasing the risk of slab breakage during hot rolling. Furthermore, there is a problem in that the P acts as an element that impairs the surface characteristics of galvanized steel sheets.

[0054] In an example embodiment of the present disclosure, since the above-described problems may occur when the P content exceeds 0.150%, the P may be included at 0.150% or less. Meanwhile, as the P may inevitably be added during the steel manufacturing process, 0% of the P content may be excluded.

Sulfur (S): 0.010% or less (excluding 0%)

[0055] Sulfur (S) is an impurity inevitably added to steel, and it is effective to manage the S content as low as possible. In particular, S in steel is highly likely to cause red-hot brittleness.

[0056] In an example embodiment of the present disclosure, since the above-described problems may occur when the S content exceeds 0.010%, the S may be included at 0.010% or less. Meanwhile, considering the level of S that is inevitably added during the steel manufacturing process, 0% of the S content may be excluded.

Aluminum (sol.Al): 0.100% or less (excluding 0%)

[0057] Aluminum (sol.Al) is an element added for grain size refinement and deoxidation of steel.

[0058] In an example embodiment of the present disclosure, since it is not possible to manufacture aluminum-killed steel in a stable state when the sol.Al content is 0%, 0% of the Al content may be excluded. Meanwhile, when the sol.Al content exceeds 0.100%, it is advantageous for increasing the strength of steel due to a grain refinement effect; however, excessive formation of inclusions occurs during continuous casting, thereby increasing the likelihood of surface defects in galvanized steel sheets. In addition, there is a concern that economic feasibility may decline due to the increase in manufacturing costs.

[0059] Therefore, in an example embodiment of the present disclosure, the sol.Al may be included in an amount greater than 0% to 0.100%. According to another example embodiment of the present disclosure, the sol.Al may be 0.005% or more, or 0.010% or more. According to another example embodiment, the sol.Al may be 0.095% or less, or 0.090% or less.

Nitrogen (N): 0.010% or less (excluding 0%)

[0060] Nitrogen (N) is an impurity inevitably added to steel, and it is effective to manage the N content as low as possible.

[0061] In an example embodiment of the present disclosure, since there is a concern that steel refining costs may increase significantly when the N content is reduced to an extremely low level, the N content may be limited to a range that is feasible for operation in consideration of this. As one example, the N content may be limited to 0.010% or less. However, considering the level inevitably added during the steel manufacturing process, 0% of the N content may be excluded.

[0062] A steel sheet according to an example embodiment of the present disclosure may further include one or more of Ti and Nb in addition to the alloy composition described above for the purpose of further improving the mechanical properties of the steel sheet.

Titanium (Ti): 0.040% or less and Niobium (Nb): 0.040% or less

[0063] Titanium (Ti) and Niobium (Nb) are elements effective for increasing the strength of steel and for grain refinement through the formation of fine precipitates.

[0064] In an example embodiment of the present disclosure, when the content of Ti and Nb each exceeds 0.040% when added, there is a problem in that manufacturing costs increase and the ductility of the steel is significantly reduced due to the excessive formation of precipitates.

[0065] Therefore, in an example embodiment of the present disclosure, when one or more of Ti and Nb are added, they may each be included in an amount of 0.040% or less. According to another example embodiment of the present disclosure, the Ti and Nb may each be 0.035% or less, or 0.030% or less.

[0066] The remaining component of the present disclosure is iron (Fe). However, since the unintended impurities from raw materials or the surrounding environment may inevitably be mixed in a normal manufacturing process, the unintended impurities may not be excluded. Since these impurities are known to those skilled in the ordinary manu-

facturing process, not all thereof are specifically mentioned in this specification.

[0067] The steel sheet according to an example embodiment of the present disclosure may be comprised of the above-described alloying elements, and the relationship between some of the alloying elements may be limited to specific conditions.

[0068] In an example embodiment of the present disclosure, the content relationship of C, Si, Cr, Mo, Ti, and Nb in the alloy composition may be defined by Relational Equation 1 below.

[Relational Equation 1]

$$2 \times \{ (Si + Cr + (3 \times Mo) + Ti + Nb) / C \} \geq 15.0$$

(In Relational Equation 1, each element represents the weight content, and 0 is substituted when it is not added.)

[0069] As the inventors of the present disclosure have repeatedly studied and recognized that reducing the hardness difference between phases is effective for achieving excellent work-hardening rate and burring property while securing a low yield ratio and high ductility in composite structure steel, a combination of specific alloying elements capable of enhancing solid-solution strengthening of ferrite in the composite structure has been formulated as Relational Equation 1.

[0070] According to an example embodiment of the present disclosure, when the value of Relational Equation 1 is controlled to 15.0 or more, the concentrations of Si, Mo, and Cr within the ferrite increase. As a result, solid-solution strengthening is induced, thereby effectively reducing the difference in hardness between phases and hard phases (e.g., martensite phase). Additionally, Ti or Nb-based precipitates are formed within the ferrite grains to relatively increase the hardness of the ferrite, thereby maximizing the effect of reducing the difference in hardness between phases.

[0071] Accordingly, according to an example embodiment of the present disclosure, the value of Relational Equation 1 may be 15.0 or more, and according to another example embodiment, the value may be 16.0 or more, or 16.5 or more.

[0072] Hereafter, the microstructure characteristics of a steel sheet according to an example embodiment of the present disclosure will be described in detail.

[0073] The inventors of the present disclosure have discovered that controlling the fraction range of each phase is effective in improving the work-hardening rate and hole expansion ratio (burring property) of the steel sheet according to an example embodiment of the present disclosure, namely the composite structure steel.

[0074] Accordingly, the steel sheet according to an example embodiment of the present invention comprises 25 to 60% ferrite, 25 to 60% bainite, and 20% or less martensite in terms of area fraction, and may further include the retained austenite as the balance structure.

[0075] When the ferrite fraction of the steel sheet according to an example embodiment of the present disclosure is less than 25%, the high ductility may not be achieved and the work-hardening rate may not be improved. On the other hand, when the fraction exceeds 60%, the target level of strength may not be secured.

[0076] In an example embodiment of the present disclosure, the bainite phase is a structure advantageous for reducing the hardness difference between phases in composite structure steel. When the fraction is less than 25%, the effect of reducing the hardness difference between phases is insufficient, and thus the burring property may not be improved. On the other hand, when the fraction exceeds 60%, the fraction of martensite, which is a relatively hard phase, becomes low, and the intended strength may not be secured. In particular, the bainite phase is formed between the ferrite and martensite phases, thereby effectively reducing the interphase hardness difference between the soft ferrite phase and the hard martensite phase.

[0077] In an example embodiment of the present disclosure, when the fraction of the martensite phase, which is advantageous for securing the strength of the steel sheet, exceeds 20%, the strength increases excessively, the ductility decreases, and the interphase hardness difference with the soft ferrite phase widens, resulting in inferior burring properties. Such a martensite phase may be formed with an appropriate fraction finely and evenly dispersed within the steel. In particular, in an example embodiment of the present disclosure, the number of fine martensite grains having an equivalent diameter of 3 μm or less may be 2.0×10^5 or more per unit area (1 mm^2). When the number of fine martensite grains is less than 2.0×10^5 per unit area (1 mm^2), the improvement of the work hardening ability of the steel sheet may not be achieved due to the presence of a large number of relatively coarse martensite phases.

[0078] The steel sheet according to an example embodiment of the present disclosure may include the retained austenite phase as the balance structure, and the fraction thereof is not specifically limited.

[0079] In particular, the steel sheet according to an example embodiment of the present disclosure may satisfy Relational Equation 2 below for the content of C, Si, Cr, and Mo in the ferrite by controlling the relationship of specific elements in the alloy composition.

[Relational Equation 2]

$$2 \times \{ (\text{Si}_F + \text{Cr}_F + (3 \times \text{Mo}_F)) / \text{C}_F \} \geq 500$$

(In Relational Equation 2, each element represents the weight content contained within the ferrite.)

[0080] That is, according to an example embodiment of the present disclosure, the content of elements that are favorable for solid solution strengthening within the ferrite phase is increased, thereby inducing a solid solution strengthening effect, and precipitates are also formed within the ferrite, thereby increasing the hardness of the ferrite as a soft phase.

[0081] In an example embodiment of the present disclosure, when the value of Relational Equation 2 is less than 500, the hardness difference between the ferrite and martensite phases is not effectively reduced, resulting in inferior burring property of the steel sheet.

[0082] The steel sheet according to an example embodiment of the present disclosure may possess characteristics of a low hardness difference between phases of the composite structure through the control of the alloy composition system and microstructure.

[0083] In particular, in the steel sheet according to an example embodiment of the present disclosure, the hardness relationship among the ferrite, bainite, and martensite phases may satisfy Relational Equation 3 below.

[Relational Equation 3]

$$H_M / (H_F + H_B) \leq 2.0$$

(In Relational Equation 3, H_M represents the hardness value of martensite, H_F represents the hardness value of ferrite, and H_B represents the hardness value of bainite.)

[0084] In an example embodiment of the present disclosure, a value of Relational Equation 3 exceeding 2.0 indicates a large difference in hardness between phases of the composite structure, and in this case, the burring property of the steel sheet cannot be secured.

[0085] In addition, the steel sheet according to an example embodiment of the present disclosure includes ferrite and bainite phases each present in at least a predetermined fraction as part of the microstructure, while a fine martensite phase is uniformly dispersed therein. As a result, deformation is initiated at low stress in the early stage of plastic deformation, thereby reducing the yield ratio and exhibiting a high work-hardening rate. This change in microstructure alleviates local stress and deformation, thereby delaying the formation, growth, and aggregation of pores, and as a result, the effect of improving the ductility of the steel sheet may be obtained.

[0086] In particular, in the steel sheet according to an example embodiment of the present disclosure, the relationship among the work-hardening rate (n), elongation (El), hole expansion ratio (HER), and yield ratio (YR) in a deformation range of 4 to 6% may satisfy Relational Equation 4 below.

[Relational Equation 4]

$$(n \times \text{El} \times \text{HER}) / \text{YR} \geq 150.0$$

(In Relational Equation 4, the units of each physical property are not considered.)

[0087] The steel sheet according to an example embodiment of the present disclosure may have high strength, exhibit a low yield ratio and high ductility, and simultaneously possess excellent characteristics regarding the work-hardening rate and hole expansion ratio.

[0088] As one example, the steel sheet may have a yield strength of 450 MPa or more, a tensile strength of 780 MPa or more, a yield ratio of 0.70 or less, and an elongation of 15% or more, and may satisfy the above-described Relational Equation 4.

[0089] Meanwhile, the steel sheet according to an example embodiment of the present disclosure may be the cold-rolled steel sheet, the hot-dip galvanized steel sheet in which a zinc-based plating layer is formed on at least one surface of the cold-rolled steel sheet, or the alloyed hot-dip galvanized steel sheet obtained by performing alloying treatment on the hot-dip galvanized steel sheet.

[0090] Although not specifically limited, the zinc-based plating layer may be a zinc plating layer containing mainly zinc, or a zinc alloy plating layer containing aluminum and/or magnesium in addition to zinc.

[0091] Hereinafter, a method for manufacturing a steel sheet according to another aspect of the present invention will be described in detail. It should be noted that the following manufacturing method corresponds to one example for manufacturing a steel sheet according to an example embodiment of the present disclosure.

[0092] According to an example embodiment of the present disclosure, the steel sheet may be manufactured by undergoing the [heating - hot rolling - cooling - coiling - cold rolling - annealing - cooling] process with respect to a prepared steel slab, and each process step is described in detail below.

5 [Heating of Steel Slab]

[0093] After preparing a steel slab according to an example embodiment of the present disclosure, the steel slab may be heated. The heating process of the steel slab is a process intended to facilitate the hot rolling process described later and to sufficiently obtain the physical properties of the target steel sheet. As one example, the steel slab may have the same alloy composition and alloy component Relational Equation (Relational Equation 1) as the steel sheet according to an example embodiment of the present disclosure, and the description of each alloy element and the component Relational Equation is replaced by the above-described matters.

[0094] In an example embodiment of the present disclosure, the heating of the steel slab may be performed in a temperature range of 1050 to 1300°C. When the heating temperature is below 1050°C, the friction between the steel sheet and the rolling mill increases, causing a problem where the load applied to the rollers during hot rolling increases rapidly. On the other hand, when the temperature exceeds 1300°C, not only does the energy cost required to raise the temperature increase, but the amount of surface scale also increases, which may lead to material loss.

[0095] Accordingly, in an example embodiment of the present disclosure, the heating process of the steel slab may be performed in a temperature range of 1050 to 1300°C. According to another example embodiment of the present disclosure, the heating process of the steel slab may be performed at 1100°C or higher, and according to yet another example embodiment, it may be performed at 1250°C or lower.

[Hot Rolling]

[0096] The hot-rolled steel sheet may be obtained by hot rolling the heated steel slab.

[0097] In an example embodiment of the present disclosure, the hot-rolled steel sheet may be manufactured by performing a finishing hot rolling at or above the Ar3 transformation point during the hot rolling. In an example embodiment of the present disclosure, when the finishing hot rolling process is performed at a temperature below the Ar3 transformation point, two-phase rolling of ferrite and austenite is performed, which may lead to material non-uniformity.

[0098] As one example, the finishing hot rolling may be performed in a temperature range of 800 to 1000°C. When the temperature exceeds 1000°C, there is a risk that material non-uniformity may be caused by the formation of abnormal coarse grains due to high-temperature rolling, which leads to a problem of coil warping during subsequent cooling.

[Coiling]

[0099] The manufactured hot-rolled steel sheet may be coiled.

[0100] In an example embodiment of the present disclosure, the coiling process may be performed in a temperature range of 400 to 700°C. When the coiling temperature is below 400°C, the strength of the hot-rolled steel sheet becomes excessively high, which may cause a rolling load during the subsequent cold rolling process. Furthermore, excessive costs and time are required to cool the hot-rolled steel sheet to the coiling temperature, which causes an increase in process costs. On the other hand, when the temperature exceeds 700°C, excessive scale may form on the surface of the hot-rolled steel sheet, which is highly likely to cause surface defects and cause the deterioration in plating properties.

[Cold rolling]

[0101] The coiled hot-rolled steel sheet may be cold-rolled to manufacture a cold-rolled steel sheet.

[0102] In an example embodiment of the present disclosure, the cold rolling may be performed at a cold reduction rate (total reduction rate) of 40 to 80%. During cold rolling, if the cold reduction rate is less than 40%, it becomes difficult to secure the target thickness, and it also becomes difficult to correct the shape of the steel sheet. On the other hand, when the cold reduction rate exceeds 80%, there is a high possibility of cracks occurring at the edge portion of the steel sheet, and there is a problem of generating load during the cold rolling.

[Continuous Annealing]

[0103] The manufactured cold-rolled steel sheet may be subjected to continuous annealing. According to an exam-

ple embodiment of the present disclosure, the continuous annealing treatment may be performed in a continuous alloying molten plating furnace.

[0104] In an example embodiment of the present disclosure, the continuous annealing treatment may be performed in a temperature range of 780 to 835°C. That is, by performing the continuous annealing treatment of the cold-rolled steel sheet in a two-phase region temperature range where ferrite and austenite coexist, carbon may be distributed while simultaneously forming ferrite as well as austenite during the recrystallization of the structure.

[0105] In the continuous annealing process according to an example embodiment of the present disclosure, when the temperature is below 780°C, recrystallization is not sufficiently achieved, and the austenite phase is not sufficiently formed, making it impossible to achieve the target microstructure phase composition after the continuous annealing process. On the other hand, when the temperature exceeds 835°C, productivity decreases, and due to the excessive formation of the austenite phase, there is a problem where the fraction of the martensite phase becomes excessive after the subsequent cooling process. In this case, while the yield strength increases, the ductility decreases, making it impossible to secure the intended low yield ratio and high ductility characteristics. Furthermore, the surface concentration of elements such as Si, Mn, and B, which impede the wettability of hot-dip galvanizing in the alloy composition, becomes excessive, thereby deteriorating the plating surface quality.

[0106] Accordingly, in an example embodiment of the present disclosure, the continuous annealing treatment may be performed in a temperature range of 780 to 835°C. According to another example embodiment of the present disclosure, the continuous annealing treatment may be performed at 785°C or higher, and according to another example embodiment, at 830°C or lower, or at 820°C or lower.

[0107] In the continuous annealing in the two-phase temperature range according to an example embodiment of the present disclosure, the austenite phase may be formed with an area fraction of 70 to 95%, and the ferrite phase may be formed with an area fraction of 5 to 30%.

[Cooling and Holding]

[0108] The cold-rolled steel sheet subjected to continuous annealing may be cooled in the above two-phase temperature range.

[0109] In an example embodiment of the present disclosure, the cooling may be performed in stages. As an example, the process may include primary cooling the continuously annealed cold-rolled steel sheet to a temperature range of 630 to 690°C at a cooling rate of 1 to 14°C/s, and then secondary cooling the first-cooled cold-rolled steel sheet to a temperature range of 350 to 480°C at a cooling rate of 10°C/s or more. In this case, the cooling rate during the secondary cooling may be faster than the cooling rate during the primary cooling.

[0110] In this way, the type and fraction of the microstructure formed may be controlled by performing stepwise cooling to a specific temperature range according to the cooling rate during the continuous annealing process according to an example embodiment of the present disclosure, in which a certain fraction of a ferrite phase is formed along with austenite.

[0111] In an example embodiment of the present disclosure, the ferrite phase may be additionally introduced into a cold-rolled steel sheet by performing the primary cooling process on a continuously annealed cold-rolled steel sheet at a cooling rate of 1 to 14°C/s to a temperature range of 630 to 690°C.

[0112] When the cooling rate during the primary cooling is less than 1°C/s, the austenite phase formed during the continuous annealing process transforms into an excessive fraction of ferrite, making it impossible to adequately secure bainite and martensite phases in the final microstructure. On the other hand, when the cooling rate exceeds 14°C/s, the amount of additionally formed ferrite phase becomes insufficient, which may lead to a reduction in the ductility of the steel sheet.

[0113] Furthermore, when the cooling end temperature during the primary cooling is less than 630°C, the ferrite phase is not sufficiently formed; conversely, when the temperature exceeds 690°C, there is a problem that the cooling rate should be excessively increased during the subsequent secondary cooling process, and there is a concern that the fractions of bainite and martensite phases in the final microstructure may not be sufficient.

[0114] According to an example embodiment of the present disclosure, during the primary cooling process of the continuously annealed cold-rolled steel sheet, a ferrite phase with an area fraction of 20 to 30% may be additionally formed, and the remaining austenite phase is dispersed along with the formation of the ferrite phase.

[0115] In an example embodiment of the present disclosure, after the primary cooling of the continuously annealed cold-rolled steel sheet, the secondary cooling may be performed at a cooling rate of 10°C/s or more up to a temperature range of 350 to 480°C, and a bainite phase may be introduced by holding the cold-rolled steel sheet in such a cooled state.

[0116] When the cooling rate during the secondary cooling is less than 10 °C/s, pearlite may be generated during the cooling process, and the bainite phase may not be sufficiently formed. Meanwhile, the upper limit of the cooling rate during the secondary cooling is not particularly limited, and may be appropriately selected by a person skilled in

the art in consideration of the specifications of the cooling equipment. As one example, it may be performed at 100°C/s or less.

[0117] In addition, when the cooling end temperature during the secondary cooling is less than 350°C, the martensite phase is excessively formed, and the martensite phase is tempered during the subsequent holding process, making it impossible to secure the intended low yield ratio and high ductility. On the other hand, when the temperature exceeds 480°C, the bainite phase is not sufficiently formed, and thus the effect of reducing the inter-phase hardness difference due to the bainite phase may not be obtained.

[0118] In an example embodiment of the present disclosure, the holding time of the secondary cooled cold-rolled steel sheet may be held for 100 seconds or more. When the holding time is less than 100 seconds, the bainite may not be obtained in a sufficient fraction. The upper limit of the holding time is not specifically limited and may be determined by a person skilled in the art as the time at which the bainite phase is formed in a fraction intended.

[0119] In an example embodiment of the present disclosure, the holding process performed after the secondary cooling may be performed in the temperature range where the secondary cooling is completed, so the temperature range is not specifically limited. However, as one example, it may be performed at 400°C or lower.

[0120] According to an example embodiment of the present disclosure, during the holding process after the secondary cooling of the primary cooled cold-rolled steel sheet, the bainite phase with an area fraction of 25 to 60% may be formed, and the formation of the bainite phase in this manner increases the dispersion effect of the remaining austenite phase (approximately 10 to 20 percent). As a result, the austenite phase remaining during the subsequent cooling process may be formed with a fine and uniform distribution when it transforms into martensite.

[Final Cooling]

[0121] The cold-rolled steel sheet, which has undergone the above-described stepwise (primary and secondary) cooling and holding processes, may be finally cooled.

[0122] In an example embodiment of the present disclosure, the final cooling of the cold-rolled steel sheet that has undergone the stepwise cooling and holding processes may be performed at a cooling rate of 3°C/s or higher to a temperature of Ms-100°C or lower, and the martensite phase may be introduced during this process.

[0123] If the cooling rate during the above-described final cooling is less than 3°C/s or the cooling end temperature exceeds Ms-100°C, the martensite phase may not be secured to the intended level. In an example embodiment of the present disclosure, the upper limit of the cooling rate and the lower limit of the cooling end temperature during the final cooling are not specifically limited; however, in terms of forming a certain fraction of the martensite phase, the cooling may be performed at a cooling rate of 50°C/s or lower, for example, and as another example, the final cooling may be performed to room temperature.

[0124] According to an example embodiment of the present disclosure, the austenite remaining after transforming into the ferrite and bainite phases during the stepwise cooling and holding process may transform into the martensite phase during the final cooling process. In this case, the austenite phase that transforms into the martensite phase during the final cooling process is uniformly and finely distributed within the steel sheet due to the dispersion effect during the previous stepwise cooling and holding process, so the martensite phase formed during the final cooling process may also be formed with a fine and uniform distribution. The martensite phase formed during the final cooling process may be formed with an area fraction of 20% or less, and the fine martensite phase may be formed at a ratio of 90% or more within the martensite phase. As an example of the present disclosure, the fine martensite phase may refer to a martensite phase having an average grain size of 3 μm or less.

[0125] Meanwhile, the austenite phase remaining after forming the martensite phase during the final cooling process described above remains as the retained austenite phase of the final microstructure. As one example, the fraction of the retained austenite phase may be 2% or less (including 0%).

[0126] According to an example embodiment of the present disclosure, a steel sheet (cold-rolled steel sheet) having a composite structure may be obtained by controlling the alloy composition system and the manufacturing conditions. The composite structure of the steel sheet may have a low difference in hardness between the soft phase and the hard phase. Further, by introducing appropriate fractions of ferrite and bainite phases, and by forming a martensite phase that is finely and uniformly dispersed, it may be possible to achieve an improvement in the work-hardening rate due to stress concentration relaxation, as well as an improvement in burring properties (hole expansion ratio).

[0127] In an example embodiment of the present disclosure, a plated steel sheet may be obtained by plating the cold-rolled steel sheet. As an example, the hot-dip galvanizing may be performed on the cold-rolled steel sheet that has undergone the stepwise cooling and holding process prior to the final cooling.

[Hot-dip Galvanizing]

[0128] The cold-rolled steel sheet according to an example embodiment of the present disclosure, that is, the cold-

rolled steel sheet that has undergone the stepwise cooling and holding process, may be immersed in a molten zinc-based plating bath to manufacture a hot-dip galvanized steel sheet.

[0129] In an example embodiment of the present disclosure, the hot-dip galvanizing process may be performed under normal conditions, but as one example, it may be performed in a temperature range of 430 to 490°C. Furthermore, the composition of the molten zinc-based plating bath during the hot-dip galvanizing is not particularly limited and may be a pure zinc plating bath or a zinc-based alloy plating bath containing Si, Al, Mg, etc.

[Alloying Heat-Treatment]

[0130] Additionally, if necessary, the alloyed hot-dip galvanized steel sheet may be obtained by performing an alloying heat-treatment on the hot-dip galvanized steel sheet produced by the hot-dip galvanizing according to an example embodiment of the present disclosure.

[0131] In an example embodiment of the present disclosure, the conditions for the alloying heat-treatment process are not specifically limited, and ordinary conditions are acceptable. As an example, the alloying heat-treatment process may be performed in a temperature range of 480 to 600°C.

[Temper Rolling]

[0132] Furthermore, if necessary, a temper rolling process may be performed, and the temper rolling process may be performed not only on the cold-rolled steel sheet that has undergone the final cooling, but also on the hot-dip galvanized steel sheet or the alloyed hot-dip galvanized steel sheet that has undergone the final cooling.

[0133] According to an example embodiment of the present disclosure, a large amount of dislocations may be formed within the steel through the temper rolling process to further improve bake hardenability, and as an example, it may be performed with a reduction rate of less than 1% (excluding 0%). When the reduction rate during the temper rolling is 1% or more, it is advantageous in terms of dislocation formation, but side effects such as plate breakage may occur due to the limitations of equipment capacity.

Mode for Invention

[0134] Hereinafter, the present disclosure will be described in more detail with reference to Examples. However, it should be noted that the following Examples are only for illustrating the present disclosure in more detail and are not intended to limit the scope of the present disclosure. This is because the scope of the present disclosure is determined by the matters described in the claims and the matters reasonably inferred therefrom.

(Example)

[0135] Steel slabs having an alloy composition system shown in Table 1 below were heated to a temperature of 1050 to 1250°C, and each of the heated slabs was finish hot-rolled in a temperature range of Ar₃ + 50°C to 950°C to manufacture a hot-rolled steel sheet. Thereafter, each hot-rolled steel sheet was pickled under conventional conditions, coiled at a temperature in the range of 400 to 700°C, and then cold-rolled at a cold reduction ratio of 40 to 80% to manufacture a cold-rolled steel sheet.

[0136] Subsequently, each cold-rolled steel sheet was subjected to continuous annealing under the conditions shown in Table 2 below, followed by stepwise cooling (primary and secondary cooling) and a holding process.

[0137] Thereafter, the sheets were cooled to room temperature at a cooling rate of 5 to 10°C/s, and then temper-rolled at a reduction ratio of 0.2% to manufacture final cold-rolled steel sheets (composite structure steel).

[Table 1]

Steel Grade	Alloy Composition (wt%)											Relational Equation 1
	C	Si	Mn	Mo	Cr	Ti	Nb	P	S	sol. Al	N	
1	0.090	0.64	2.45	0.001	0.250	0.001	0.020	0.013	0.004	0.026	0.004	20.3
2	0.11 0	1.05	2.00	0.03 0	0.01 1	0.00 2	0.02 0	0.05 0	0.00 7	0.03 1	0.00 5	21.3
3	0.06 5	0.11	2.10	0.02 0	0.75 0	0.01 0	0.03 0	0.03 0	0.00 4	0.05 4	0.00 4	29.5
4	0.08 0	0.20	1.80	0.15 0	0.45 0	0.02 0	0.00 1	0.04 0	0.00 3	0.04 3	0.00 8	28.0
5	0.11 0	0.55	2.20	0.02 0	0.25 0	0.03 0	0.01 0	0.01 0	0.00 5	0.02 5	0.00 5	16.4
6	0.15 0	0.30	2.30	0.03 0	0.17 0	0.02 5	0.02 1	0.10 0	0.00 7	0.02 2	0.00 3	8.1

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(continued)

Steel Grade	Alloy Composition (wt%)											Relational Equation 1
	C	Si	Mn	Mo	Cr	Ti	Nb	P	S	sol. Al	N	
7	0.07 0	0.10	2.50	0.02 0	0.22 0	0.02 4	0.03 3	0.12 0	0.00 5	0.02 0	0.00 2	<u>12.5</u>
8	<u>0.19</u> 0	0.04	1.50	0.11 0	0.32 0	0.00 4	0.01 3	0.11 0	0.00 7	0.06 4	0.00 3	<u>7.4</u>
9	<u>0.14</u> 2	0.18	1.80	0.02 0	0.40 0	0.01 0	0.01 7	0.06 0	0.00 3	0.05 2	0.00 6	<u>9.4</u>
10	0.10 0	0.10	2.40	0.14 0	0.12 0	0.00 1	0.02 0	0.04 0	0.00 1	0.04 4	0.00 4	<u>13.2</u>

[Table 2]

Steel Grade	Coiling Temperature (°C)	Annealing Temperature (°C)	Primary Cooling		Secondary Cooling		Holding		Division
			End Temperature (°C)	Cooling Rate (°C/s)	End Temperature (°C)	Cooling Rate (°C/s)	Temperature (°C)	Time (sec)	
1	410	813	675	7	422	24	365	260	Inventive Steel 1
2	650	810	685	2	401	26	367	348	Inventive Steel 2
3	620	790	677	4	370	40	363	488	Inventive Steel 3
4	690	809	685	3	407	26	373	350	Inventive Steel 4
5	650	835	630	13	460	16	371	150	Inventive Steel 5
5	650	<u>770</u>	650	8	<u>490</u>	15	381	<u>91</u>	Comparative Steel 1
6	630	<u>850</u>	675	3	399	26	365	350	Comparative Steel 2
7	650	810	648	8	460	17	372	400	Comparative Steel 3
8	630	799	650	4	<u>500</u>	30	388	320	Comparative Steel 4
9	650	<u>840</u>	675	2	399	26	365	370	Comparative Steel 5
10	620	<u>770</u>	649	4	470	17	386	400	Comparative Steel 6

[0138] For each cold-rolled steel sheet manufactured as described above, the microstructure was measured and the mechanical properties were evaluated, and the results are shown in Table 3.

[0139] First, for the microstructure of each cold-rolled steel sheet, specimens were taken at the 1/4t position (t: thickness of steel sheet (unit: mm)) in the thickness direction and subjected to Nital etching, and then the fractions of ferrite, bainite, and martensite phases were measured using FE-SEM and an image analyzer. The fraction of retained austenite was measured using XRD.

[0140] In addition, the concentrations of specific elements (C, Si, Mo, Cr) in the ferrite were measured using transmission electron microscopy (TEM), energy dispersive spectroscopy (EDS), and electron energy loss spectroscopy (EELS). After the hardness of each phase was measured ten times using a Vickers micro hardness tester, the average value was obtained, and Relational Equation 3 was calculated using these values.

[0141] Further, from the martensite area results measured using the image analyzer, the size of each particle was converted into an equivalent diameter and measured. In this case, the number of martensite particles having a size of 3 μm or less was calculated within a unit area of 1 mm^2 .

[0142] Meanwhile, tensile properties of each cold-rolled steel sheet were evaluated in the C direction in accordance with JIS standards using the same specimens as those used for the microstructure measurement.

[0143] In addition, the work-hardening rate n was measured for the same specimen in a deformation range of 4 to 6%, and the hole expansion ratio (HER) was evaluated in accordance with the JSF T1001-1996 standard.

[Table 3]

Division		Microstructure Characteristics					Mechanical Property Characteristics								
		F	B	M	R-A	Relationship Equation 2	Fine M Number	YS (MPa)	TS (MPa)	El (%)	YR	n	HER (%)	Relationship Equation 3	Relationship Equation 4
Inventive Steel 1		41	46	12	1	595	2.42×10^5	496	826	21	0.60	0.18	35	1.6	220.5
Inventive Steel 2		53	29	16	2	767	3.83×10^5	502	809	21	0.62	0.20	35	1.4	237.1
Inventive Steel 3		28	59	13	0	613	2.61×10^5	548	813	19	0.67	0.18	36	1.2	183.8
InventiveSteel 4		42	43	15	0	733	2.98×10^5	514	841	19	0.61	0.20	33	1.1	205.6
InventiveSteel 5		32	47	20	1	573	2.01×10^5	508	826	22	0.62	0.15	30	1.3	159.7
Comparative Steel 1		59	10	31	0	572	1.43×10^5	430	850	17	0.51	0.15	26	2.3	131.1
ComparativeSteel 2		20	73	6	1	373	1.01×10^5	645	850	11	0.76	0.09	64	2.1	83.4
Comparative Steel 3		51	23	26	0	253	1.79×10^5	509	818	18	0.62	0.15	18	2.2	78.4
Comparative Steel 4		45	20	35	0	463	1.19×10^5	472	843	15	0.56	0.18	23	2.5	110.9
Comparative Steel 5		25	67	8	0	426	1.21×10^5	580	856	11	0.68	0.09	59	2.9	85.9
Comparative Steel 6		62	8	30	0	427	1.39×10^5	439	804	16	0.55	0.21	22	2.4	134.4
In the microstructure, F denotes ferrite, B denotes bainite, M denotes martensite, and R-A denotes retained austenite, and each phase is expressed as an area fraction (%).															
The number of fine martensite (M) phases was measured per unit area of 1 mm ² .															

[0144] As shown in Tables 1 to 3, Inventive Steels 1 to 5, which satisfy both the alloy composition system and the manufacturing conditions according to an example embodiment of the present disclosure, exhibited the intended microstructures. Accordingly, Inventive Steels 1 to 5 have a tensile strength of 780 MPa or more, a low yield ratio of 0.70 or less, and high ductility. In addition, the hardness difference between the phases in the microstructure was minimized, such that the value of Relational Equation 3 was 2.0 or less, and Relational Equation 4 was satisfied due to the improved hole expansion ratio and work-hardening rate.

[0145] As such, the cold-rolled steel sheet according to one embodiment of the present invention exhibits a low yield ratio and high ductility, which are characteristics of DP steel, and, despite its multiphase microstructure, exhibits excellent burring property and work-hardening rate due to the small hardness difference between phases.

[0146] In contrast, Comparative Steel 1, which satisfies the alloy composition system of the present invention but does not satisfy the manufacturing conditions, and Comparative Steels 2 to 6, which deviate from Relational Equation 1 of the present invention and also do not satisfy the manufacturing conditions, failed to form the intended microstructures, and thus exhibited inferior physical properties in at least one aspect.

[0147] In particular, in Comparative Steels 1 to 6, the ferrite, bainite, or martensite phases were not formed in the intended fractions, or the compositional relationship of specific elements in the ferrite did not satisfy Relational Equation 2 according to an example embodiment of the present disclosure. Accordingly, the work-hardening rate was inferior, failing to satisfy Relational Equation 4, and a large hardness difference between phases was also observed.

[0148] FIG. 1 graphically illustrates the variation in mechanical properties (Relational Equation 3) as a function of the compositional relationship (Relational Equation 1) of specific elements.

[0149] As illustrated in FIG. 1, when the value of Relational Equation 1 is 15 or more, the value of Relational Equation 3 is 2 or less. In other words, according to an example embodiment of the present disclosure, controlling the compositional relationship of specific elements reduces the interphase hardness difference in the composite structure steel.

[0150] FIG. 2 graphically illustrates the variation in mechanical properties (Relational Equation 4) as a function of the compositional relationship (Relational Equation 1) of specific elements.

[0151] As illustrated in FIG. 2, when the value of Relational Equation 1 is 15 or more, the value of Relational Equation 4 is 150 or more. That is, according to an example embodiment of the present disclosure, the work-hardening rate and burring property of the composite structure steel may be improved by controlling the compositional relationship of specific elements.

[0152] FIGS. 1 and 2 illustrate Inventive Steels 1 to 5, which are steel sheets according to an example embodiment of the present disclosure, and Comparative Steels 2 to 6, which do not satisfy Relational Equation 1 according to an example embodiment of the present disclosure.

Claims

1. A steel sheet, comprising:

by wt%, carbon (C): 0.060 to 0.120%, silicon (Si): 1.20% or less (excluding 0%), manganese (Mn): 1.80 to 2.50%, molybdenum (Mo): 0.200% or less (excluding 0%), chromium (Cr): 0.800% or less (excluding 0%), phosphorus (P): 0.150% or less (excluding 0%), sulfur (S): 0.010% or less (excluding 0%), aluminum (sol.Al): 0.100% or less (excluding 0%), nitrogen (N): 0.010% or less (excluding 0%), and the balance being Fe and other unavoidable impurities,

wherein the steel sheet satisfies Relational Equation 1 below, and has a microstructure including, in area fraction, 25 to 60% ferrite, 25 to 60% bainite, 20% or less martensite, and the balance being retained austenite,

$$[\text{Relational Equation 1}]$$

$$2 \times \{ (\text{Si} + \text{Cr} + (3 \times \text{Mo}) + \text{Ti} + \text{Nb}) / \text{C} \} \geq 15.0$$

where each element represents the weight content, and 0 is substituted when is not added.

2. The steel sheet of claim 1, wherein the number of fine martensite grains having an equivalent diameter of 3 μm or less is 2.0×10^5 or more per unit area (1 mm^2).

3. The steel sheet of claim 1, further comprising:

one or more of titanium (Ti): 0.040% or less and niobium (Nb): 0.040% or less.

4. The steel sheet of claim 1, wherein the content of C, Si, Mo, and Cr in the ferrite satisfies Relational Equation 2 below,

[Relational Equation 2]

$$2 \times \{ (Si_F + Cr_F + (3 \times Mo_F)) / C_F \} \geq 500$$

where each element represents the weight content contained within the ferrite.

5. The steel sheet of claim 1, wherein a hardness relationship of the ferrite, bainite, and martensite satisfies Relational Equation 3 below,

[Relational Equation 3]

$$H_M / (H_F + H_B) \leq 2.0$$

where H_M represents the hardness value of martensite, H_F represents the hardness value of ferrite, and H_B represents the hardness value of bainite.

6. The steel sheet of claim 1, wherein a relationship between work-hardening rate (n), elongation (El), hole expansion ratio (HER), and yield ratio (YR) in a deformation range of 4 to 6% satisfies Relational Equation 4 below,

[Relational Equation 4]

$$(n \times El \times HER) / YR \geq 150.0$$

where the units of each physical property are not considered.

7. The steel sheet of claim 1, wherein the steel sheet has a yield strength of 450 MPa or more, a tensile strength of 780 MPa or more, a yield ratio of 0.70 or less, and an elongation of 15% or more.

8. A method for manufacturing a steel sheet, comprising:

preparing a steel slab including, by wt%, carbon (C): 0.060 to 0.120%, silicon (Si): 1.20% or less (excluding 0%), manganese (Mn): 1.80 to 2.50%, molybdenum (Mo): 0.200% or less (excluding 0%), chromium (Cr): 0.800% or less (excluding 0%), phosphorus (P): 0.150% or less (excluding 0%), sulfur (S): 0.010% or less (excluding 0%), aluminum (sol.Al): 0.100% or less (excluding 0%), nitrogen (N): 0.010% or less (excluding 0%), and the balance being Fe and other unavoidable impurities, and satisfying Relational Equation 1 below; heating the steel slab to a temperature range of 1050 to 1300°C;

obtaining a hot-rolled steel sheet by finishing hot-rolling the heated steel slab at a temperature of Ar3 transformation point or higher;

coiling the hot-rolled steel sheet at a temperature range of 400 to 700°C;

obtaining a cold-rolled steel sheet by cold-rolling the coiled hot-rolled steel sheet with a total reduction rate of 40 to 80%;

continuously annealing the cold-rolled steel sheet in a temperature range of 780 to 835°C;

primarily cooling the continuously annealed cold-rolled steel sheet to a temperature range of 630 to 690°C at a cooling rate of 1 to 14°C/s;

secondarily cooling the primarily cooled cold-rolled steel sheet to a temperature range of 350 to 480°C at a cooling rate of 10°C/s or more;

holding the secondarily cooled cold-rolled steel sheet for 100 seconds or more; and

finally cooling the held cold-rolled steel sheet to a temperature of Ms-100°C or lower at a cooling rate of 3°C/s or higher,

[Relational Equation 1]

$$2 \times \{ (\text{Si} + \text{Cr} + (3 \times \text{Mo}) + \text{Ti} + \text{Nb}) / \text{C} \} \geq 15.0$$

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where each element represents the weight content, and 0 is substituted when it is not added.

9. The method of claim 8, further comprising:
obtaining a galvanized steel sheet by galvanizing the held cold-rolled steel sheet before final cooling.

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10. The method of claim 9, further comprising:
selectively alloying heat-treating the galvanized steel sheet.

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11. The method of claim 8, further comprising:
temper rolling the finally cooled cold-rolled steel sheet with a reduction rate of less than 1%.

12. The method of claim 8, wherein the steel slab further includes one or more of titanium (Ti): 0.040% or less and niobium (Nb): 0.040% or less.

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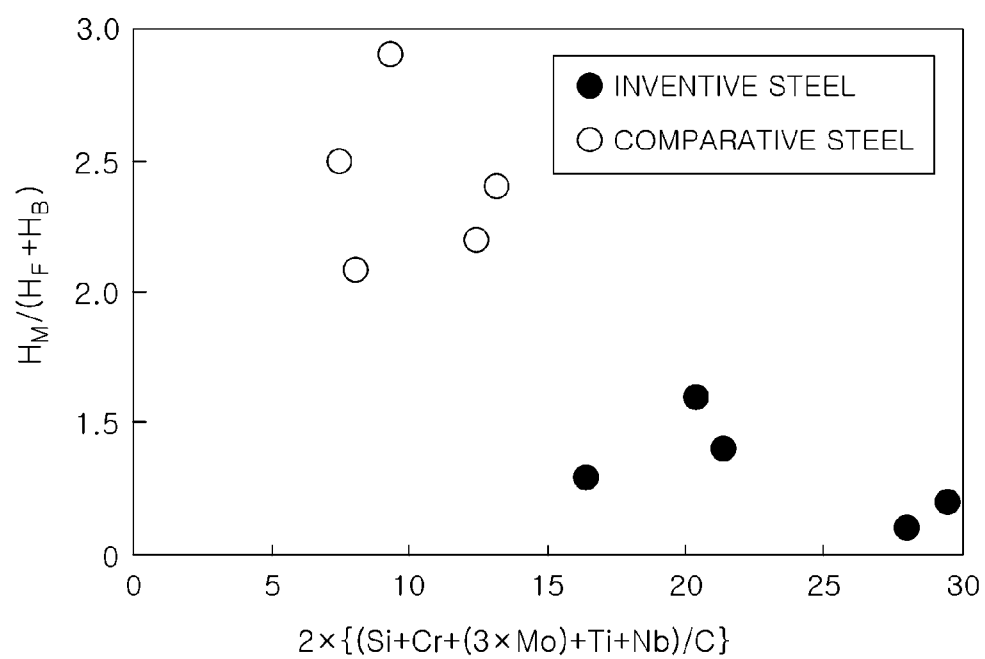
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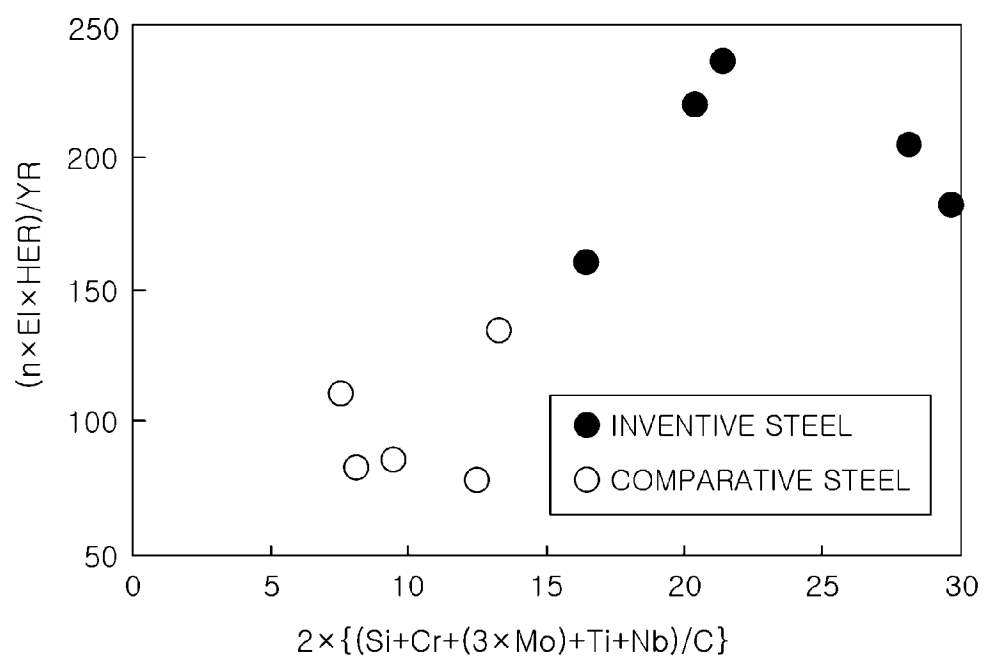
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[FIG. 1]



[FIG. 2]



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/096659

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/38(2006.01)i; C22C 38/22(2006.01)i; C22C 38/06(2006.01)i; C22C 38/00(2006.01)i; C22C 38/28(2006.01)i;
C22C 38/26(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 38/38(2006.01); B2D 11/124(2006.01); C21D 6/00(2006.01); C21D 8/02(2006.01); C22C 38/00(2006.01);
C22C 38/04(2006.01); C22C 38/06(2006.01); C22C 38/58(2006.01); C22C 38/60(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: 강판(steel sheet), 페라이트(ferrite), 베이나이트(bainite), 마르텐사이트(martensite), 몰리브덴(molybdenum), 크롬(chromium), 티타늄(titanium), 니오븀(niobium), 가열(heating), 냉각(cooling), 소둔(annealing), 냉간압연(cold rolled)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 7367893 B1 (JFE STEEL CORP.) 24 October 2023 (2023-10-24) See paragraphs [0089], [0094], [0097], [0107], [0111]-[0113], [0130], [0132] and [0136], claims 1, 3 and 21 and tables 2-3.	1-12
A	KR 10-2021-0123371 A (NIPPON STEEL CORPORATION) 13 October 2021 (2021-10-13) See paragraphs [0188]-[0191] and claims 1-2.	1-12
A	CN 116888283 A (SALZGITTER FLACHSTAHL G.M.B.H.) 13 October 2023 (2023-10-13) See claims 1 and 13.	1-12
A	KR 10-2018-0095668 A (JFE STEEL CORPORATION) 27 August 2018 (2018-08-27) See paragraphs [0092]-[0102] and claims 1-3.	1-12
A	JP 2015-200006 A (KOBE STEEL LTD.) 12 November 2015 (2015-11-12) See paragraphs [0094]-[0098] and claims 1 and 5-6.	1-12

☐ 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 12 March 2025	Date of mailing of the international search report 13 March 2025
Name and mailing address of the ISA/KR Korean Intellectual Property Office Government Complex-Daejeon Building 4, 189 Cheongsaro, Seo-gu, Daejeon 35208 Facsimile No. +82-42-481-8578	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2024/096659

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