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(54) **STEEL SHEET AND MANUFACTURING METHOD THEREFOR**

(57) The present invention provides a steel sheet suitable for a structural member of a vehicle, which has high strength of 590 MPa or higher in tensile

strength, along with excellent work hardening rate and hole expandability, and also provides a method for manufacturing the steel sheet.

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Description

Technical Field

[0001] The present disclosure relates to a steel sheet suitable as a material for a structural member of a vehicle, and more particularly, to a high-strength composite structure steel sheet with a tensile strength of 590 MPa or more and a method for manufacturing the same.

Background Art

[0002] Currently, regulations on the environment and safety in the automotive industry are becoming increasingly stringent, and in particular, as regulations on carbon dioxide emissions are being intensified, fuel efficiency regulations for automobiles are also being gradually strengthened.

[0003] According to the U.S. Insurance Institute for Highway Safety (IIHS), crash safety regulations for occupant protection have been strengthened, and in particular, since 2013, severe crash performance such as a 25% small overlap has been required.

[0004] At present, the only viable solution to address environmental and safety issues is the lightening of automobiles. To achieve this, higher-strength steel is required, and, for the application of such high-strength steel, excellent formability should also be required.

[0005] A method of strengthening steel includes solid solution strengthening, precipitation strengthening, strengthening by grain refinement, transformation strengthening, or the like. However, among the above-described methods, solid solution strengthening and strengthening by grain refinement have disadvantages, in that it is difficult to manufacture high-strength steel having a tensile strength of 590 MPa or more.

[0006] High-strength steel achieved through precipitation strengthening is based on a technique in which the steel is strengthened by the precipitation of carbides and nitrides through the addition of carbide- and nitride-forming elements such as copper (Cu), niobium (Nb), titanium (Ti), and vanadium (V), or in which strength is secured by grain refinement through the suppression of grain growth by fine precipitates. This technology has an advantage in that high strength may be easily obtained at a low manufacturing cost. However, since the recrystallization temperature increases rapidly due to the fine precipitates, high-temperature annealing is required in order to induce sufficient recrystallization to secure ductility of the steel. In addition, since precipitation-strengthened steel forms precipitates such as carbides and nitrides in a ferrite matrix, there is a limitation in obtaining high strength of 600 MPa or more.

[0007] Meanwhile, transformation-strengthened high-strength steels have been developed, including dual phase steel (DP steel) having a ferrite-martensite dual phase microstructure in which hard martensite is formed in a ferrite matrix, transformation induced plasticity steel (TRIP steel) utilizing the transformation-induced plasticity of retained austenite, and complex phase steel (CP steel) composed of ferrite and hard bainite or martensite phases.

[0008] Recently, as automotive steel sheets, steel sheets having higher strength are required to improve fuel efficiency and durability, while the use of high-strength steel sheets having a minimum tensile strength of 590 MPa or more as vehicle body structural members or reinforcements has been increasing for crash safety and passenger protection.

[0009] However, as the strength increases, processing defects such as cracks or wrinkles occur during the forming of automotive parts (e.g., press forming), resulting in limitations in manufacturing complex parts.

[0010] Accordingly, from the viewpoint of improving the workability of high-strength steel, when it is possible to improve workability indices such as work hardening rate, elongation, and hole expansion ratio while holding a low yield ratio of DP steel, which is the most widely used transformation-strengthened high-strength steel, processing defects occurring during forming into parts may be prevented. Furthermore, such high-strength steel may expand its applicability to complex parts.

[0011] As the related art, Patent Document 1 may be cited. The present technology discloses a steel sheet having a composite microstructure mainly composed of martensite, and proposes a method of dispersing fine copper precipitate particles having a particle size of 1 to 100 nm within the microstructure in order to improve workability. However, in this case of the technology, 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 leads to a significant increase in production cost.

[0012] As another technology, 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] As another technology, Patent Document 3 discloses a technology for achieving high strength and high

ductility by utilizing a tempered martensite phase, and more specifically discloses a cold-rolled steel sheet having excellent flatness after continuous annealing. However, in this technology, the carbon content in the steel is as high as 0.2% or more, which may lead to inferior weldability, and there is also a problem that furnace dent defects may occur due to a high content of Si.

(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. 2010-090432

Summary of Invention

Technical Problem

[0014] An aspect of the present disclosure is to provide a steel sheet suitable for a structural member of a vehicle, which has high strength of 590 MPa or more in tensile strength, along with excellent work hardening rate and a hole expansion ratio. Another aspect of the present disclosure is to provide a method for manufacturing a 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 steel sheet includes, by wt%, carbon (C): 0.100 to 0.150%, silicon (Si): 0.30 to 1.00%, manganese (Mn): 1.20 to 1.90%, phosphorus (P): 0.100% or less (excluding 0%), sulfur (S): 0.010% or less (excluding 0%), aluminum (sol.Al): 0.500% or less (excluding 0%), chromium (Cr): 0.500% or less (excluding 0%), nitrogen (N): 0.010% or less (excluding 0%), and a balance of Fe and unavoidable impurities.

[0017] In an aspect of the present disclosure, the steel sheet may satisfy Relational Equation 1 below.

[Relational Equation 1]

$$((3 \times \text{Si}) + \text{Al} + (10 \times \text{C})) / (\text{Si} + \text{Mn} + (3 \times \text{Cr})) \geq 1.00$$

[0018] (In Relational Equation 1, each element represents the weight content, and 0 is substituted when it is not added.)

[0019] In an aspect of the present disclosure, the steel sheet may have a microstructure including, in area fraction, 60 to 80% ferrite, 10 to 25% bainite, 3 to 8% retained austenite, and a balance of a martensite phase.

[0020] In an aspect of the present disclosure, the martensite phase may include an area fraction of less than 11%.

[0021] The steel sheet having such an alloy composition system and a microstructure may have a low yield ratio and high ductility, and provide excellent work hardening rate and hole expansion ratio.

[0022] The steel sheet according to an aspect of the present disclosure may have a yield ratio of 0.7 or less, 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 2 below.

[Relational Equation 2]

$$(n \times \text{El} \times \text{HER}) / \text{YR} \geq 400.0$$

[0023] (In Relational Equation 2, the units of each physical property are not considered.)

[0024] According to another aspect of the present disclosure, a method for manufacturing a steel sheet includes: preparing, a steel slab; heating the steel slab to a temperature range of 1100 to 1300°C; obtaining a hot-rolled steel sheet by finishing hot-rolling the heated steel slab at an Ar3 transformation point temperature or higher; coiling the hot-rolled steel sheet at a temperature within a range of 400 to 700°C; cold rolling the coiled hot-rolled steel sheet with a total reduction ratio of 40 to 80% to obtain a cold-rolled steel sheet; continuously annealing the cold-rolled steel sheet at an intercritical temperature within a range 760 to 820°C; primarily cooling the continuously annealed cold-rolled steel sheet to a temperature range of 630 to 690°C at a cooling rate of 10°C/s or less (excluding 0°C/s); secondarily cooling the primarily cooled cold-rolled steel sheet to a temperature range of 350 to 450°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 $M_s-100^{\circ}\text{C}$ or lower at a cooling rate of 3°C/s or higher.

[0025] In an aspect of the present disclosure, the steel slab may have the above-described alloy composition and may satisfy Relational Equation 1.

[0026] In an aspect 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, and optionally alloying heat-treatment the galvanized steel sheet.

[0027] In an aspect 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

[0028] According to an aspect of the present disclosure, it is possible to provide a cold-rolled steel sheet (complex phase steel) having excellent workability while having a low yield ratio and high ductility, which are characteristics of DP steel.

[0029] According to an aspect of the present disclosure, the cold-rolled steel sheet has the effect of being suitable for application as a material for automobiles, particularly for structural members.

Best Mode for Invention

[0030] The inventors of the present invention have conducted intensive studies on methods for improving workability, namely a work hardening rate and a hole expansion ratio, while holding a low yield ratio and high elongation of DP steel that has been used as a material for structural members of a vehicle.

[0031] Through the repeated research, the inventors confirmed that by optimizing the alloy composition system and manufacturing conditions for steel sheets with a tensile strength of 590 MPa or more, it is possible to establish a microstructure advantageous for securing desired physical properties. As a result, the present disclosure is provided.

[0032] Hereinafter, the present disclosure will be described in detail.

[0033] According to an aspect of the present disclosure, a steel sheet may include, by wt%, carbon (C): 0.100 to 0.150%, silicon (Si): 0.30 to 1.00%, manganese (Mn): 1.20 to 1.90%, phosphorus (P): 0.100% or less (excluding 0%), sulfur (S): 0.010% or less (excluding 0%), aluminum (sol.Al): 0.500% or less (excluding 0%), chromium (Cr): 0.500% or less (excluding 0%), and nitrogen (N): 0.010% or less (excluding 0%).

[0034] 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): 0.100 to 0.150%

[0035] Carbon (C) is a very important element added to strengthen a transformation microstructure, and contributes to the high strengthening of steel, while also being effective in promoting the formation of a martensite phase in complex phase steel.

[0036] As the C content increases, the amount of martensite formed in the steel increases. However, in an example embodiment of the present disclosure, when the C content exceeds 0.150%, the strength is improved due to the formation of a large amount of martensite; however, the difference in strength from ferrite having a relatively low carbon concentration increases. Under these circumstances, fracture easily occurs at the interface between phases upon stress application, resulting in inferior bending properties and elongation flangeability of the steel. Furthermore, as stress concentrates in the high-strength martensite, ductility and work hardening rate decrease, and weldability deteriorates, leading to welding defects during component processing at the customer company. Conversely, when the C content is less than 0.100%, it becomes very difficult to secure the target strength, and it becomes difficult to secure the retained austenite phase, which is advantageous for securing ductility.

[0037] Therefore, in an example embodiment of the present disclosure, C may be included in an amount of 0.100 to 0.150%. According to another example embodiment of the present disclosure, C may be 0.105% or more, or 0.110% or more. According to another example embodiment, C may be 0.145% or less, or 0.140% or less.

Silicon (Si): 0.30 to 1.00%

[0038] Silicon (Si) is a ferrite-stabilizing element that promotes the formation of ferrite in steel and contributes to the formation of martensite by promoting the enrichment of carbon in untransformed austenite. In addition, 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. In addition, Si is a useful element for ensuring strength without reducing the ductility of steel.

[0039] Meanwhile, silicon (Si) delays carbide precipitation during bainite transformation during the manufacturing process of steel, thereby effectively enrich the carbon in austenite, and is thus an element advantageous for the

formation of a retained austenite phase. For these reasons, silicon (Si) needs to be essentially added. However, when the Si content is less than 0.30%, it is difficult to secure a sufficient amount of the retained austenite phase, which is advantageous for ensuring ductility. In an example embodiment of the present disclosure, when the Si content exceeds 1.00%, scale defects may occur on the steel surface, potentially leading to a deterioration in plating quality.

Additionally, the chemical treatment properties of steel may be reduced, making it impossible to ensure paintability. [0040] Accordingly, in an example embodiment of the present disclosure, the Si may be included in an amount of 0.30 to 1.00%. According to another example embodiment of the present disclosure, the Si may be 0.35% or more, or 0.40% or more. According to another example embodiment, the Si may be 0.90% or less, or 0.85% or less.

Manganese (Mn): 1.20 to 1.90%

[0041] 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 the complex phase 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.

[0042] In an example embodiment of the present disclosure, when the Mn content is less than 1.20%, 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 1.90%, 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 bands (Mn oxide bands) in the microstructure 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.

[0043] Accordingly, in an example embodiment of the present disclosure, the Mn may be included in an amount of 1.20 to 1.90%. According to another example embodiment of the present disclosure, the Mn may be included in an amount of 1.25% or more, or 1.30% or more. According to another example embodiment, the Mn may be 1.85% or less.

Phosphorus (P): 0.100% or less (excluding 0%)

[0044] Phosphorus (P) is a substitutional element exhibiting the greatest solid solution strengthening effect and is advantageous for improving in-plane anisotropy. Furthermore, P is the most advantageous element for securing strength without significantly impairing the formability of steel. However, when P is added in excess, the possibility of brittle fracture increases significantly, leading to a higher likelihood of plate fracture of the slab during hot rolling. In addition, there is a problem in that it acts as an element that impairs the surface characteristics of plated steel sheets.

[0045] In an example embodiment of the present disclosure, since the above-described problems may occur when the P content exceeds 0.100%, the P may be included at 0.100% 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%)

[0046] Sulfur (S) is an impurity inevitably added to steel and impairs the ductility and weldability of steel; therefore, it is effective to manage its content as low as possible. In particular, S in steel is highly likely to cause red-hot brittleness.

[0047] 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): 0.500% or less (excluding 0%)

[0048] Aluminum (sol.Al) is an element added for grain size refinement and deoxidation of steel. Additionally, similar to Si, it acts as a ferrite-stabilizing element, distributing carbon in ferrite to austenite, thereby improving the hardenability of martensite. In addition, it is an element useful for improving the ductility of steel by effectively suppressing the precipitation of carbides within the bainite when held in the bainite region.

[0049] In an example embodiment of the present disclosure, when the content of sol.Al exceeds 0.500%, excessive inclusions are formed during continuous steelmaking operations, increasing the likelihood of surface defects in plated steel sheets. In addition, there is a concern that economic feasibility may decline due to the increase in manufacturing costs.

[0050] Meanwhile, 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.

[0051] Therefore, in an example embodiment of the present disclosure, the sol.Al may be included in an amount greater than 0% to 0.500%. 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 0.490% or less, or 0.450% or less.

Chromium (Cr): 0.500% or less (excluding 0%)

[0052] Chromium (Cr) 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 complex phase 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-El) is suppressed, which is advantageous for manufacturing complex phase steel with a low yield ratio.

[0053] In an example embodiment of the present disclosure, when the Cr content exceeds 0.500%, the above-described effects become saturated, and there is a risk that the hot-rolled strength will increase excessively, leading to a decrease in cold-rollability. Furthermore, as the fraction of Cr-based carbides increases and becomes coarsened, the martensite becomes coarsened after annealing, causing a problem of reduced elongation of 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.

[0054] Therefore, in an example embodiment of the present disclosure, the Cr may be included in an amount greater than 0% to 0.500%. According to another example embodiment of the present disclosure, the Cr may be 0.005% or more, or 0.010% or more. According to another example embodiment, the Cr may be 0.450% or less, or 0.400% or less.

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

[0055] Nitrogen (N) is an element effective in stabilizing austenite; however, when its content is excessive, not only does the refining cost of steel increase sharply, but also the formation of AlN increases the risk of crack formation in slabs during continuous casting. Considering this, in an example embodiment of the present disclosure, N may be limited to 0.010% or less. However, considering the level of N that is inevitably added during the steel manufacturing process, 0% of the N content may be excluded.

[0056] 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 manufacturing process, not all of them are specifically mentioned in this specification.

[0057] The steel sheet according to an example embodiment of the present disclosure may be composed of the above-described alloying elements, and the relationship between some of the alloying elements may be limited to specific conditions.

[0058] In an example embodiment of the present disclosure, the content relationship of C, Si, Mn, Al, and Cr in the alloy composition may be defined by the following Relational Equation 1.

[Relational Equation 1]

$$((3 \times \text{Si}) + \text{Al} + (10 \times \text{C})) / (\text{Si} + \text{Mn} + (3 \times \text{Cr})) \geq 1.00$$

[0059] (In Relational Equation 1, each element represents the weight content, and 0 is substituted when it is not added.)

[0060] As a result of repeated studies, the inventors of the present disclosure have found that, in order to secure the low yield ratio and high ductility of the complex phase steel, the formation of an appropriate ferrite phase and a predetermined amount of retained austenite is effective. Accordingly, the combination of specific alloying elements that influence the above-described microstructure formation was factorized as Relational Equation 1.

[0061] Specifically, in order to secure a predetermined amount of retained austenite phase as the microstructure of the steel sheet according to an example embodiment of the present disclosure, it is necessary to enrich C within the austenite. When a predetermined amount of C is contained in steel, Si and Al delay carbide precipitation during the bainitic transformation and promote the enrichment of C into austenite. Therefore, along with C, Si and Al are essential elements for securing the retained austenite phase. Furthermore, Si and Al are ferrite-stabilizing elements and are

also effective in increasing the ferrite fraction.

[0062] Meanwhile, Mn and Cr, which are hardenability-enhancing elements added to steel to secure strength, delay the transformation of ferrite after annealing, particularly during cooling (slow cooling) after intercritical annealing according to an example embodiment of the present disclosure, thereby limiting the formation of ferrite. In this case, the volume fractions of the relatively hard bainite and martensite phases increase, and their sizes become coarsened, making it difficult to obtain a target retained austenite phase; consequently, although the strength is high, ductility and workability (e.g., work hardening rate, hole expansion ratio, etc.) are deteriorated.

[0063] Based on this, when the value of Relational Equation 1 according to an example embodiment of the present disclosure is 1.00 or higher, the target ferrite phase and retained austenite phase may be obtained, and as a result, the workability of the steel may be improved. However, when the value is less than 1.00, the ferrite and retained austenite phases may not be secured to the target level, resulting in inferior workability of steel. According to another example embodiment of the present disclosure, the value of Relational Equation 1 may be 1.10 or greater.

[0064] Meanwhile, in an example embodiment of the present disclosure, the upper limit of Relational Equation 1 may be determined within the content setting range of each element constituting Relational Equation 1, and such upper limit is not specifically limited.

[0065] Hereafter, the microstructure characteristics of a steel sheet according to an example embodiment of the present disclosure will be described in detail.

[0066] The inventors of the present disclosure have found that controlling the volume fraction range of each phase is effective in improving workability in a steel sheet according to an embodiment of the present disclosure, i.e., the complex phase steel, while having high strength and high ductility.

[0067] Accordingly, the steel sheet according to an aspect of the present disclosure may include, in area fraction, 60 to 80% ferrite, 10 to 25% bainite, 3 to 8% retained austenite, and a balance of a martensite phase.

[0068] As described above, in order to improve the ductility of the steel sheet according to an example embodiment of the present disclosure, the fractions of the ferrite phase and the retained austenite phase should be precisely controlled.

[0069] In an example embodiment of the present disclosure, the ferrite phase is a soft phase and is a structure advantageous for securing ductility. As one example, when the ferrite fraction is less than 60%, the target elongation may not be secured, whereas when the fraction exceeds 80%, the target level of strength may not be secured.

[0070] In addition, in an example embodiment of the present disclosure, the retained austenite phase may contribute to securing the ductility of steel by causing transformation induced plasticity during the processing process when steel is processed (formed) to manufacture parts, etc. As one example, when the retained austenite phase fraction is less than 3%, it is difficult to secure the target elongation, whereas when the retained austenite phase fraction exceeds 8%, the risk of liquid metal embrittlement occurring during spot welding of parts for automobile manufacturing increases.

[0071] As such, while limiting the ferrite and retained austenite phases to appropriate fractions improves the ductility of steel, it is advantageous to include the bainite phase in an appropriate fraction to improve the hole expansion ratio of the steel. When Si and Al are added in a predetermined amount to the steel, during the formation of the bainite phase, the carbon enrichment toward austenite surrounding the bainite is promoted to delay the precipitation of carbides and improve the thermal stability of the austenite, so the retained austenite phase may be secured at room temperature. As an example, when the bainite phase fraction is less than 10%, the amount of carbon enriched into the austenite is reduced, which may result in a lower retained austenite phase fraction. On the other hand, when the bainite phase fraction exceeds 25%, the strength of steel increases, resulting in inferior ductility.

[0072] The bainite phase has hardness intermediate between that of the relatively soft ferrite phase and the relatively hard martensite phase, and thus serves to reduce the hardness difference between the ferrite phase and the martensite phase (i.e., the inter-phase hardness difference). As a result, the hole expansion ratio of the steel may be improved. When the fraction of the above-described bainite phase is less than 10%, the effect of reducing the hardness difference between the phases may not be sufficiently obtained, and thus the hole expansion ratio of the steel may not be improved. On the other hand, when the fraction exceeds 25%, the effect of reducing the hardness difference between phases may be significantly obtained, but it becomes difficult to secure the target low yield ratio due to the increase in yield strength.

[0073] The steel sheet according to an example embodiment of the present disclosure may include a martensite phase as a structure other than the above-described structures (phases). In an example embodiment of the present disclosure, the martensite phase may be present as a remaining fraction excluding the ferrite phase, retained austenite phase, and bainite phase, and the fraction thereof is not particularly limited.

[0074] As a non-limiting example, the martensite phase may be included in an area fraction of less than 11%, and more advantageously, 10.5% or less.

[0075] In an example embodiment of the present disclosure, the martensite phase mainly refers to a fresh martensite phase, but does not exclude a tempered martensite phase. The tempered martensite phase may be included at an impurity level.

[0076] Meanwhile, the martensite phase is a phase with high hardness, and when external stress is applied during the processing (forming) of steel, local stress becomes significantly higher compared to the ferrite and bainite phases. To resolve this problem, the inventors of the present disclosure have conducted in-depth research and recognized that stress and deformation may be controlled so that they are not concentrated in one part by finely and evenly dispersing the martensite phase within the steel. Accordingly, in an example embodiment of the present disclosure, the fraction (Ms) of fine martensite having an average particle size of 2 μm or less is controlled with respect to the total martensite fraction (Mt), and, as an example, the proportion (Ms/Mt) of fine martensite having an average particle size of 2 μm or less, may be controlled to be 70% or more. Here, the average particle size refers to the average value of the equivalent diameter.

[0077] That is, by containing the martensite phase according to an example embodiment of the present disclosure and ensuring that it is finely dispersed within the steel, the work hardening rate and ductility of the steel may be improved. When the proportion (Ms/Mt) of the fine martensite is less than 70%, the fine dispersion effect of the martensite is insufficient, and the work hardening rate and ductility of the steel are inferior due to the concentration of local stress and deformation.

[0078] In addition, in an example embodiment of the present disclosure, the number of fine martensite grains with an average grain size of 2 μm or less in the martensite phase 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 in 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.

[0079] The steel sheet according to an example embodiment of the present disclosure may exhibit characteristics such as a low yield ratio and a high work hardening rate, as deformation begins at low stress in the initial stage of plastic deformation by controlling the microstructure. In particular, by controlling the microstructure, local stress and deformation may be alleviated, thereby exhibiting a high work hardening rate, and ductility can be improved by delaying the formation, growth, and coalescence of pores.

[0080] In particular, the steel sheet according to an example embodiment of the present disclosure may have a yield ratio (yield strength/tensile strength) of 0.7 or less, and the relationship between the work hardening rate (n) in the 4 to 6% deformation range, elongation (El), hole expansion ratio (HER), and yield ratio (YR) may satisfy the following Relational Equation 2.

[Relational Equation 2]

$$(n \times \text{El} \times \text{HER}) / \text{YR} \geq 400.0$$

[0081] (In Relational Equation 2, the units of each physical property are not considered.)

[0082] Additionally, the steel sheet according to an example embodiment of the present disclosure may have high strength and exhibit high ductility, and as one example, may have a tensile strength of 590 MPa or more and an elongation of 25% or more.

[0083] Meanwhile, the steel sheet according to an example embodiment of the present disclosure may be a cold-rolled steel sheet, a hot-dip galvanized steel sheet including a zinc-based plating layer on at least one surface of the cold-rolled steel sheet, or an alloyed hot-dip galvanized steel sheet obtained by alloying the hot-dip galvanized steel sheet.

[0084] 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.

[0085] 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.

[0086] According to an example embodiment of the present disclosure, the steel sheet may be manufactured by performing the [heating - hot rolling - cooling - coiling - cold rolling - annealing - cooling] process on a prepared steel slab, and each process step is described in detail below.

[Heating of Steel Slab]

[0087] 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 plate. 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.

[0088] In an example embodiment of the present disclosure, the process of heating the steel slab may be performed under normal conditions, and as one example, may be performed within a temperature range of 1100 to 1300°C. When the heating temperature is below 1100°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.

[Hot Rolling]

[0089] The hot-rolled steel sheet may be obtained by hot rolling the heated steel slab.

[0090] 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, intercritical rolling of ferrite and austenite is performed, which may lead to material non-uniformity.

[0091] As one example, the finishing hot rolling may be performed within 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]

[0092] The manufactured hot-rolled steel sheet may be coiled.

[0093] In an example embodiment of the present disclosure, the coiling process may be performed within 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 subsequent cold rolling. 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]

[0094] The coiled hot-rolled steel sheet may be cold-rolled to manufacture the cold-rolled steel sheet.

[0095] In an example embodiment of the present disclosure, the cold rolling may be performed with a cold reduction rate (total reduction rate) of 40 to 80%. When the cold reduction rate during the cold rolling is less than 40%, it becomes difficult to secure the target thickness, and it 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 of the steel sheet, and there is a problem of generating load during the cold rolling.

[Continuous Annealing]

[0096] The manufactured cold-rolled steel sheet may be subjected to continuous annealing. According to an example embodiment of the present disclosure, the continuous annealing treatment may be performed in a continuous alloying molten plating furnace.

[0097] In an example embodiment of the present disclosure, the continuous annealing treatment may be performed within a temperature range of 760 to 820°C. That is, by performing the continuous annealing treatment of the cold-rolled steel sheet in an intercritical temperature range where ferrite and austenite coexist, carbon may be distributed while simultaneously forming ferrite as well as austenite during the recrystallization of the microstructure.

[0098] In the continuous annealing process according to an example embodiment of the present disclosure, when the temperature is below 760°C, not only is recrystallization not sufficiently achieved, but also the austenite phase is not sufficiently formed, and thus it becomes impossible to secure an appropriate fraction of the target microstructure phase composition, for example, the bainite and martensite phases, after the continuous annealing process. On the other hand, when the temperature exceeds 820°C, productivity decreases, and due to the excessive formation of the austenite phase, there is a problem where the fractions of the martensite phase and the bainite phase become excessive after the subsequent cooling process. In this case, the yield strength increases and 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 and Mn, which impede the wettability of hot-dip galvanizing in the alloy composi-

tion, becomes excessive, thereby deteriorating the plating surface quality.

[0099] Accordingly, in an example embodiment of the present disclosure, the continuous annealing treatment may be performed within a temperature range of 760 to 820°C. According to another example embodiment of the present disclosure, the continuous annealing treatment may be performed at 770°C or higher.

[Cooling and Holding]

[0100] The cold-rolled steel sheet subjected to continuous annealing may be cooled in the intercritical temperature range.

[0101] In an example embodiment of the present disclosure, the cooling may be performed in stages. As one example, the process may include primary cooling the cold-rolled steel sheet that has undergone continuous annealing treatment to a temperature range of 630 to 690°C at a cooling rate of 10°C/s or less (excluding 0°C/s), and then secondary cooling the primarily cooled cold-rolled steel sheet to a temperature range of 350 to 450°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.

[0102] In this way, the type and fraction of the microstructure formed can be controlled by stepwise cooling within a specific temperature range according to the cooling rate during a continuous annealing process of a cold-rolled steel sheet in which a certain fraction of a ferrite phase is formed together with austenite, according to an embodiment of the present disclosure.

[0103] In an example embodiment of the present disclosure, the ferrite phase may be additionally introduced into the annealed cold-rolled steel sheet by performing the primary cooling process on a continuously annealed cold-rolled steel sheet at a cooling rate of 10°C/s or less to a temperature range of 630 to 690°C.

[0104] When the cooling rate during the primary cooling exceeds 10°C/s, the additionally introduced ferrite phase becomes insufficient, and there is a risk that the ductility of the steel sheet will decrease. Meanwhile, the lower limit of the cooling rate is not specifically limited. However, in order to control the fraction of the ferrite phase in the final microstructure to 80% or less, it may be performed at 0.5°C/s or higher.

[0105] 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.

[0106] According to an example embodiment of the present disclosure, during the primary cooling process of the continuously annealed cold-rolled steel sheet, the ferrite phase is additionally formed, while the austenite phase remaining after the formation of the ferrite phase is dispersed.

[0107] 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 450°C, and a bainite phase may be introduced by holding the cold-rolled steel sheet in such a cooled state.

[0108] 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.

[0109] 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 450°C, the bainite phase is not sufficiently formed, and thus the effect of the bainite phase in an appropriate fraction, such as the effect of reducing the hardness difference between phases, may not be obtained.

[0110] In an example embodiment of the present disclosure, the holding process of the secondary cooled cold-rolled steel sheet may be performed 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.

[0111] 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.

[0112] According to an example embodiment of the present disclosure, a certain fraction of a bainite phase may be formed during a holding process after the secondary cooling of the primarily cooled cold-rolled steel sheet, and due to the formation of the bainite phase, the dispersion effect of the remaining austenite phase may be further enhanced. 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]

[0113] The cold-rolled steel sheet, which has undergone the above-described stepwise (primary and secondary) cooling and holding processes, may be finally cooled.

[0114] 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 range of Ms-100°C or lower, and the martensite phase may be introduced during this process. Here, Ms represents the martensite transformation initiation temperature, and the cooling may be performed up to the room temperature. The room temperature is not specifically limited and may be approximately 25 to 35°C.

[0115] 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 during the final cooling is not specifically limited; however, in terms of forming a certain fraction of the martensite phase, it may be performed at a cooling rate of 50°C/s or lower, for example.

[0116] 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 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. In particular, a fine martensite phase may be formed at a ratio of 70% or more relative to the total fraction of the martensite phase formed during the final cooling process. As an example of the present disclosure, the fine martensite phase may refer to a martensite phase having an average grain size of 2 μm or less.

[0117] Meanwhile, the austenite phase remaining after the formation of the martensite phase during the final cooling process remains as it is and becomes a retained austenite phase of the final microstructure, and according to the alloy composition and manufacturing conditions of one embodiment of the present invention, the retained austenite phase may be formed in an area fraction of 3 to 8%.

[0118] According to an example embodiment of the present disclosure, the steel sheet (cold-rolled steel sheet) having a composite structure may be obtained by controlling the alloy composition system and manufacturing conditions. Specifically, the composite structure of the cold-rolled steel sheet according to an example embodiment of the present disclosure has a low difference in hardness between the soft phase and the hard phase, and the martensite phase may be formed with fine and uniform dispersion along with the introduction of appropriate fractions of the ferrite, retained austenite, and bainite phases. As a result, the cold-rolled steel sheet may have the effect of improving the hole expansion ratio along with the improvement in the work hardening rate due to the alleviation of stress concentration.

[0119] In an example embodiment of the present disclosure, the 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]

[0120] 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 (galvanized steel sheet).

[0121] 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 within 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]

[0122] 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 manufactured by the hot-dip galvanizing according to an example embodiment of the present disclosure.

[0123] 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 pro-

cess may be performed within a temperature range of 480 to 600°C.

[Temper Rolling]

[0124] 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.

[0125] 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

[0126] 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)

[0127] Steel slabs having an alloy composition system shown in Table 1 below were heated to a temperature of 1100 to 1300°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.

[0128] 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. Thereafter, the sheets were cooled to room temperature at a cooling rate of 5°C/s, and then temper-rolled at a reduction ratio of 0.2% to manufacture final cold-rolled steel sheets (complex phase steel).

[Table 1]

Steel Grade	Alloy Composition (wt%)								Relational Equation 1
	C	Si	Mn	P	S	sol.Al	Cr	N	
1	0.110	0.60	1.50	0.011	0.002	0.210	0.100	0.005	1.30
2	0.120	0.72	1.90	0.013	0.003	0.030	0.100	0.002	1.16
3	0.120	0.73	1.60	0.011	0.004	0.020	0.200	0.004	1.16
4	0.150	0.51	1.40	0.012	0.002	0.410	0.300	0.004	1.22
5	0.140	0.73	1.40	0.011	0.008	0.025	0.100	0.005	1.49
6	0.100	0.62	1.90	0.011	0.002	0.210	0.050	0.003	1.15
7	0.120	0.51	2.00	0.015	0.004	0.030	0.700	0.002	<u>0.60</u>
8	0.100	0.21	1.90	0.014	0.007	0.025	0.200	0.005	<u>0.61</u>
9	0.160	0.33	1.60	0.016	0.005	0.031	0.300	0.006	<u>0.93</u>
10	0.080	0.71	2.20	0.014	0.002	0.025	0.600	0.004	<u>0.63</u>
11	0.100	0.05	2.00	0.011	0.008	0.710	0	0.003	<u>0.91</u>
12	0.120	0.69	1.90	0.012	0.005	0.200	0.500	0.005	<u>0.85</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	650	800	630	4	390	21	380	150	Inventive Steel 1
2	580	820	680	5	400	31	390	210	Inventive Steel 2
3	560	780	680	8	420	23	420	250	Inventive Steel 3
4	520	820	650	6	400	18	380	301	Inventive Steel 4
5	450	818	680	5	380	27	380	112	Inventive Steel 5
6	670	810	670	7	420	25	400	310	Inventive Steel 6
7	650	830	650	6	<u>330</u>	33	320	257	Comparative Steel 1
8	630	800	680	5	400	31	380	<u>82</u>	Comparative Steel 2
9	650	<u>840</u>	650	7	420	22	410	123	Comparative Steel 3
10	680	820	650	4	<u>560</u>	11	450	304	Comparative Steel 4
11	580	770	680	3	400	30	380	208	Comparative Steel 5
12	550	800	680	4	<u>540</u>	13	450	322	Comparative Steel 6

[0129] For each cold-rolled steel sheet manufactured as described above, the microstructure was measured and the mechanical properties were evaluated, and the results were shown in Table 3.

[0130] 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, 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.

[0131] In this case, from the martensite area results measured using the image analyzer, the size of each particle was converted into an equivalent diameter and measured. Next, the fraction and number of martensite grains having a size of 2 μm or less were calculated within a unit area of 1 mm^2 .

[0132] 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.

[0133] 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 (Mt)	R-A	Ms/M t	Micro M Number	YS (MPa)	TS (MPa)	El (%)	YR	n	HER (%)	Relationship Equation 2
Inventive Steel 1	69	20	8	3	80	2.28×10^{-5}	380	671	27	0.57	0.237	43	482.7
Inventive Steel 2	73	16	8	3	76	2.30×10^{-5}	370	629	28	0.59	0.221	48	503.4
Inventive Steel 3	73	16	7	4	77	2.43×10^{-5}	357	638	29	0.56	0.231	51	610.1
Inventive Steel 4	67	23	7	3	82	2.08×10^{-5}	384	632	27	0.61	0.220	55	535.6
Inventive Steel 5	71	16	10	3	87	2.49×10^{-5}	340	689	26	0.49	0.233	45	556.3
Inventive Steel 6	72	16	7	5	75	2.12×10^{-5}	363	605	29	0.60	0.226	43	469.7
Comparative Steel 1	81	4	15	<u>0</u>	43	1.58×10^{-5}	497	699	22	0.71	0.206	46	293.6
Comparative Steel 2	83	3	14	<u>0</u>	53	1.32×10^{-5}	379	683	23	0.55	0.200	38	317.8
Comparative Steel 3	75	7	18	<u>0</u>	61	1.14×10^{-5}	483	722	21	0.67	0.198	43	266.9
Comparative Steel 4	79	6	15	<u>0</u>	50	1.46×10^{-5}	368	676	24	0.54	0.176	39	305.1
Comparative Steel 5	80	6	14	<u>0</u>	33	1.76×10^{-5}	362	620	27	0.58	0.184	45	385.4
Comparative Steel 6	83	5	11	<u>1</u>	41	1.27×10^{-5}	350	675	21	0.52	0.179	39	281.9
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 .													

[0134] As shown in Tables 1 through 3, Inventive Steels 1 through 6, 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 through 6 have a tensile strength of 590 MPa or more, a low yield ratio of 0.70 or less, and high ductility. In addition, the steel sheet according to an example embodiment of the present disclosure satisfies Relational Equation 2 as the hole expansion ratio and the work hardening rate increase.

[0135] As such, the cold-rolled steel sheet according to an example embodiment of the present disclosure exhibits a low yield ratio and high ductility, which are characteristics of DP steel, and, despite being the complex phase steel, exhibits excellent workability due to a small hardness difference between phases.

[0136] On the other hand, Comparative Steels 1 through 6, which do not satisfy at least one of the alloy composition system and the manufacturing conditions according to an example embodiment of the present invention, failed to form the intended microstructure. As a result, Comparative Steels 1 through 6 did not satisfy the desired properties, particularly Relational Equation 2.

Claims

1. A steel sheet, comprising:

by wt%, carbon (C): 0.100 to 0.150%, silicon (Si): 0.30 to 1.00%, manganese (Mn): 1.20 to 1.90%, phosphorus (P): 0.100% or less (excluding 0%), sulfur (S): 0.010% or less (excluding 0%), aluminum (sol.Al): 0.500% or less (excluding 0%), chromium (Cr): 0.500% or less (excluding 0%), nitrogen (N): 0.010% or less (excluding 0%), and a balance of Fe and unavoidable impurities, wherein the steel sheet satisfies the following Relational Equation 1, and has, by area fraction, a microstructure composed of 60 to 80% ferrite, 10 to 25% bainite, 3 to 8% retained austenite, and a balance of a martensite phase,

[Relational Equation 1]

$$((3 \times \text{Si}) + \text{Al} + (10 \times \text{C})) / (\text{Si} + \text{Mn} + (3 \times \text{Cr})) \geq 1.00$$

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

2. The steel sheet of claim 1, wherein the martensite phase includes an area fraction of less than 11%.

3. The steel sheet of claim 1, wherein the number of fine martensite grains having an equivalent diameter of 2 μm or less is 2.0×10^5 or more per unit area (1 mm²).

4. The steel sheet of claim 1, wherein a ratio (Ms/Mt) of a total fraction (Mt) of the martensite and a fraction (Ms) of fine martensite with an average grain size of 2 μm or less is 70% or more.

5. The steel sheet of claim 1, wherein the steel sheet has a yield ratio (yield strength/tensile strength) of 0.7 or less.

6. The steel sheet of claim 1, wherein a relationship between work-hardening rate (n) in a deformation range of 4 to 6%, elongation (El), hole expansion ratio (HER), and yield ratio (YR) satisfies Relational Equation 2 below,

[Relational Equation 2]

$$(n \times \text{El} \times \text{HER}) / \text{YR} \geq 400.0$$

where the units of each physical property are not considered.

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

preparing, a steel slab including, by wt%, carbon (C): 0.100 to 0.150%, silicon (Si): 0.30 to 1.00%, manganese (Mn): 1.20 to 1.90%, phosphorus (P): 0.100% or less (excluding 0%), sulfur (S): 0.010% or less (excluding 0%), aluminum (sol.Al): 0.500% or less (excluding 0%), chromium (Cr): 0.500% or less (excluding 0%), nitrogen (N): 0.010% or less (excluding 0%), and a balance of Fe and unavoidable impurities, and satisfying the following Relational Equation 1;

heating the steel slab to a temperature range of 1100 to 1300°C;

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

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

cold rolling the coiled hot-rolled steel sheet with a total reduction ratio of 40 to 80% to obtain a cold-rolled steel sheet;
 continuously annealing the cold-rolled steel sheet at an intercritical temperature within a range 760 to 820°C;
 primarily cooling the continuously annealed cold-rolled steel sheet to a temperature range of 630 to 690°C at a cooling rate of 10°C/s or less (excluding 0°C/s);
 secondarily cooling the primarily cooled cold-rolled steel sheet to a temperature range of 350 to 450°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]

$$((3 \times \text{Si}) + \text{Al} + (10 \times \text{C})) / (\text{Si} + \text{Mn} + (3 \times \text{Cr})) \geq 1.00$$

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

8. The method of claim 7, further comprising:
 obtaining a galvanized steel sheet by galvanizing the held cold-rolled steel sheet before final cooling.
9. The method of claim 8, further comprising:
 optionally alloying heat-treatment the galvanized steel sheet.
10. The method of claim 7, further comprising:
 temper rolling the finally cooled cold-rolled steel sheet with a reduction rate of less than 1%.
11. The method of claim 7, wherein the secondary cooling is performed at a faster cooling rate than the primary cooling.

INTERNATIONAL SEARCH REPORT

International application No.

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A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/38(2006.01)i; **C22C 38/06**(2006.01)i; **C22C 38/00**(2006.01)i; **C21D 8/02**(2006.01)i; **C21D 9/46**(2006.01)i;
C23C 2/06(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); B22D 11/124(2006.01); B32B 15/01(2006.01); C21D 6/00(2006.01); C21D 8/04(2006.01);
 C21D 9/46(2006.01); C22C 38/00(2006.01); C22C 38/06(2006.01); C22C 38/58(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), 오스테나이트(austenite), 크롬(chromium), 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 [0038], [0089], [0094], [0097], [0099], [0107], [0111]-[0113], [0130], [0132] and [0136], claims 1, 3 and 21 and tables 2-3.	1-11
A	KR 10-2021-0123371 A (NIPPON STEEL CORPORATION) 13 October 2021 (2021-10-13) See paragraphs [0188]-[0191] and claims 1-2.	1-11
A	KR 10-2010-0112657 A (NIPPON STEEL CORPORATION) 19 October 2010 (2010-10-19) See paragraphs [0182]-[0185] and claims 1 and 6-7.	1-11
A	US 2020-0232060 A1 (NIPPON STEEL CORPORATION) 23 July 2020 (2020-07-23) See paragraphs [0129]-[0130] and claim 17.	1-11
A	CN 116888283 A (SALZGITTER FLACHSTAHL G.M.B.H.) 13 October 2023 (2023-10-13) See claims 1 and 13.	1-11

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

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“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 18 March 2025	Date of mailing of the international search report 19 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.

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REFERENCES CITED IN THE DESCRIPTION

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