



(11)

**EP 4 826 100 A1**

(12)

**EUROPEAN PATENT APPLICATION**  
published in accordance with Art. 153(4) EPC

(43) Date of publication:  
**21.10.2026 Bulletin 2026/43**

(21) Application number: **24904307.6**

(22) Date of filing: **16.12.2024**

(51) International Patent Classification (IPC):  
**C22C 38/58** <sup>(2006.01)</sup> **C22C 38/42** <sup>(2006.01)</sup>  
**C22C 38/50** <sup>(2006.01)</sup> **C22C 38/06** <sup>(2006.01)</sup>  
**C22C 38/00** <sup>(2006.01)</sup> **C22C 38/54** <sup>(2006.01)</sup>  
**C23C 2/06** <sup>(2006.01)</sup> **C23C 2/28** <sup>(2006.01)</sup>  
**C21D 8/02** <sup>(2026.01)</sup>

(52) Cooperative Patent Classification (CPC):  
**C21D 8/02; C22C 38/00; C22C 38/06; C22C 38/42;**  
**C22C 38/50; C22C 38/54; C22C 38/58; C23C 2/06;**  
**C23C 2/28**

(86) International application number:  
**PCT/KR2024/020370**

(87) International publication number:  
**WO 2025/127742 (19.06.2025 Gazette 2025/25)**

(84) Designated Contracting States:  
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB**  
**GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL**  
**NO PL PT RO RS SE SI SK SM TR**  
Designated Extension States:  
**BA**  
Designated Validation States:  
**GE KH MA MD TN**

(30) Priority: **15.12.2023 KR 20230183851**

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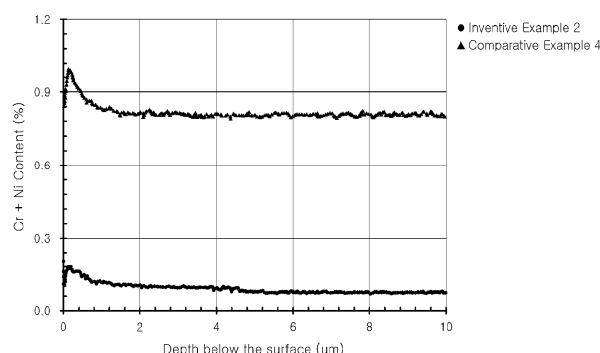
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(54) **COLD-ROLLED STEEL SHEET AND METHOD FOR MANUFACTURING SAME**

(57) Provided are a steel sheet and a method for manufacturing the same. The present invention is useful for manufacturing a cold-rolled steel sheet, a hot-dip galvanized steel sheet, and an alloyed hot-dip galva-

nized steel sheet having a tensile strength of 590 MPa or more, a uniform elongation of 18% or more, and a hole expansion ratio (HER) of 40% or more.

[Fig. 3]



**Description**

## TECHNICAL FIELD

- 5 **[0001]** The present invention relates to a cold-rolled steel sheet, a hot-dip galvanized steel sheet, and a galvanized steel sheet used for automobile body parts, and a method for manufacturing the same.

## BACKGROUND ART

- 10 **[0002]** Recently, in order to mitigate global warming, the steel industry has been accelerating the development of various steelmaking technologies that can reduce greenhouse gas emissions during the steel production process. In the automotive industry as well, there is a focus on weight reduction of automotive components to improve fuel efficiency. In particular, to reduce carbon dioxide emissions during the steel production process, steelmakers are developing and attempting to commercially apply process technologies that manufacture pig iron by reducing iron ore  
15 using hydrogen, or electric furnace processes (producing molten steel using electricity with steel scrap itself or steel scrap + direct reduced iron (DRI or HBI)) that produce products with a relatively high impurity content, in addition to the conventional blast furnace (charging iron ore + coke + limestone, etc., to produce pig iron) - converter method, which can mass-produce high-quality products with low impurity content but has a relatively high greenhouse gas emission.

- [0003]** Meanwhile, automobile manufacturers are attempting to expand the application of thin, high-strength steel sheets to individual parts for the weight reduction of automotive components. In particular, when a steel sheet or blank  
20 applied to an automotive inner structural member is stamped in a single cold operation, dimensional defects such as springback or forming cracks may occur. Therefore, the steel used for such parts is required to have excellent cold formability (e.g., high ductility, stretch flangeability or hole expansion, 90° bendability, etc.) or workability during the part forming process, and high impact energy absorption (high yield ratio) or fatigue durability when the actual part is  
25 installed in a vehicle and is in service.

**[0004]** Accordingly, various patent documents have proposed methods for satisfying the strength-elongation balance or stretch flangeability (or hole expansion ratio) of high-strength hot-dip galvanized steel sheets by optimizing alloy components, microstructure, and hot rolling, cold rolling, and annealing conditions.

- [0005]** For example, Patent Document 1 discloses a technology for hot-rolling a steel slab containing, by weight %, C: 0.06-0.09%, Mn: 1.5-2.0%, Si: 0.1% or less, P: 0.02% or less, S: 0.0020% or less, Al: 0.005-0.05%, Cr: 0.05-0.4%,  
30 Ti: 0.005-0.02%, Nb: 0.005-0.05%, N: 0.0050% or less, and Ca: 0.0001-0.0020% at 850-950°C, cooling at an average cooling rate of 5-200°C/sec, followed by coiling, pickling, and cold rolling at 600°C or less, and then performing continuous annealing and hot-dip galvanizing heat treatment. Specifically, it describes a method for manufacturing a plated steel sheet by heating to an annealing temperature of 800-900°C, cooling at an average cooling rate of  
35 2-50°C/sec, and then air-cooling in the temperature range of 450-650°C for 10-50 seconds, followed by hot-dip galvanizing or galvannealing heat treatment. According to the technology described in Patent Document 1, a 1.4 mm thick steel sheet composed of 80-90% ferrite, 10-20% fresh martensite, and 5% or less of other phases can be obtained, with a tensile strength of 595-635 MPa (yield ratio of 0.76-0.79), a TS x EL value of 18600-20910 MPa·%, and a hole expansion ratio (HER) of 74% or more. Meanwhile, Patent Document 1 limits the sulfur (S) content as a  
40 major steel component to 0.0020% or less, but there is no mention of the effect of the size, number fraction, aspect ratio, or clustering size of MnS inclusions on the hole expansion property of the steel.

- [0006]** In addition, Patent Document 2 discloses a method for manufacturing a hot-rolled steel sheet or a hot-rolled plated steel sheet by reheating a steel slab, optionally Ca-treated, containing, by weight %, C: 0.07-0.15%, Mn: 0.65-1.30%, Si: 0.005-0.35%, P: 0.03% or less, S: 0.05% or less, Al: 0.003-0.6%, Cr: 0.6-1.40%, Ti: 0.07-0.2%, B:  
45 less than 0.001% (excluding 0%), and N: 0.01% or less, to a temperature below 1300°C and hot-rolling at a temperature of Ar<sub>3</sub> or higher. Then, the hot-rolled steel sheet is cooled by continuous cooling or multi-stage cooling at a cooling rate of 20°C/sec or more and coiled at a temperature between M<sub>s</sub> and B<sub>s</sub>. According to the technology described in Patent Document 2, a hot-rolled steel sheet or a hot-rolled plated steel sheet can be obtained with a microstructure composed of a sum of ferrite and carbide-free bainite fractions of 80% or more, 3-5% tempered martensite, retained  
50 austenite, and optionally fine carbides of 30 nm or less, having a tensile strength of 760-940 MPa (yield ratio of 0.83-0.90), a TS x EL value of 12700-13800 MPa·%, and a hole expansion ratio (HER) of 50% or more. In Patent Document 2, the sulfur (S) content as a major steel component is limited to 0.0500% or less, but the actual examples show a content of less than 0.0020%. The high hole expansion property of this multi-phase complex structure steel is thought to be due to the presence of a relatively very high fraction of the bainite phase. Meanwhile, there is no detailed  
55 mention in this document of the effect of the sulfur (S) content or MnS inclusions on the hole expansion property.

[Prior Art Document]

[Patent Document]

**[0007]**

(Patent Document1) Japanese Patent No. 5239562  
 (Patent Document2) Korean Patent No. 10-2102005

## DISCLOSURE OF INVENTION

## 10 TECHNICAL PROBLEM

**[0008]** The present invention aims to provide a high-strength cold-rolled steel sheet, hot-dip galvanized steel sheet, and galvanized steel sheet with excellent hole expansion properties, and a method for manufacturing the same, by limiting the sum of Cr+Ni+Cu content to 0.7% or less, and by appropriately combining the alloy elements and controlling the manufacturing process to improve uniform elongation and hole expansion.

**[0009]** Furthermore, the technical problems to be achieved by the present invention are not limited to the technical problems mentioned above, and other unmentioned technical problems will be clearly understood by those of ordinary skill in the art from the following description.

## 20 SOLUTION TO PROBLEM

**[0010]** Accordingly, one aspect of the present invention relates to a cold-rolled steel sheet comprising, by weight %, C: 0.06 to 0.09%, Mn: 1.2 to 1.6%, Si: 1.3 to 1.7%, P: 0.02% or less, S: 0.007% or less, Al: 0.05% or less, Cr: 0.2% or less (including 0%), Ni: 0.2% or less (including 0%), Cu: 0.3% or less (including 0%), Ti: 0.02% or less (including 0%), Ca: 0.0040% or less (including 0%), N: 0.01% or less, and a sum of Cr+Ni+Cu content of 0.7% or less, with the remainder being Fe and other impurities, and satisfying the following Relational Expression 1.

[Relational Expression 1]

$$0.08 \leq (\text{Cr} + \text{Ni} + \text{Cu}) / (\text{C} + \text{Mn}) \leq 0.7 \quad (\text{by weight})$$

**[0011]** The cold-rolled steel sheet may further satisfy the following Relational Expression 2.

[Relational Expression 2]

$$0.06 \leq (\text{Al} + \text{Cu} + \text{Ti} + \text{Ca}) / (\text{Mn} + \text{S}) \leq 0.5 \quad (\text{by weight})$$

**[0012]** The difference between the (Ni+Cu) content at a thickness position 0.1 μm directly below the surface layer of the cold-rolled steel sheet and the (Ni+Cu) content at a thickness position 50 μm from the surface layer may satisfy the following Relational Expression 3.

[Relational Expression 3]

$$(\text{Ni} + \text{Cu}) \text{ at } 0.1\mu\text{m} - (\text{Ni} + \text{Cu}) \text{ at } 50\mu\text{m} \geq 0.1\% \quad (\text{by weight})$$

**[0013]** A hot-dip galvanized layer may be formed on one side of the cold-rolled steel sheet.

**[0014]** A galvanized layer may be formed on one side of the cold-rolled steel sheet.

**[0015]** The cold-rolled steel sheet may have a tensile strength of 590 MPa or more, a uniform elongation of 18% or more, and a hole expansion ratio (HER) of 40% or more.

**[0016]** Furthermore, the present invention relates to a method for manufacturing a cold-rolled steel sheet, comprising the steps of:

heating a steel slab satisfying the above composition and Relational Expression 1 to a temperature range of 1150 to 1300°C;

obtaining a hot-rolled steel sheet by finish hot-rolling the heated slab in a temperature range of 800 to 1000°C;

cooling the hot-rolled steel sheet and coiling it at a temperature of 510 to 620°C;

cold-rolling the coiled steel sheet at a cold reduction ratio of 30 to 70%; and heating the cold-rolled steel sheet to a temperature of 780 to 820°C, then performing a first slow cooling to 600-700°C, followed by a second rapid cooling to a temperature range of 350 to 450°C at an average cooling rate of 10°C/sec or more, and then holding for 100 to 700 seconds.

**[0017]** The steel slab may further satisfy the following Relational Expression 2.

[Relational Expression 2]

$$0.06 \leq (Al+Cu+Ti+Ca) / (Mn+S) \leq 0.5 \quad (\text{by weight})$$

**[0018]** The manufactured cold-rolled steel sheet may satisfy the following Relational Expression 3, where the difference is between the (Ni+Cu) content at a thickness position 0.1 μm directly below the surface layer and the (Ni+Cu) content at a thickness position 50 μm from the surface layer.

[Relational Expression 3]

$$(Ni+Cu) \text{ at } 0.1\mu\text{m} - (Ni+Cu) \text{ at } 50\mu\text{m} \geq 0.1\% \quad (\text{by weight})$$

**[0019]** The method may further comprise a step of manufacturing a hot-dip galvanized steel sheet by heating the maintained cold-rolled steel sheet to a temperature range of 400 to 470°C and then performing hot-dip galvanizing.

**[0020]** The method may further comprise a step of manufacturing a galvanized steel sheet by heating the hot-dip galvanized steel sheet to a temperature of 500 to 560°C and then performing an alloying heat treatment.

**[0021]** The cold-rolled steel sheet, the hot-dip galvanized steel sheet, and the galvanized steel sheet may also be subjected to skin pass rolling with an elongation of 0.1 to 1.5%.

#### ADVANTAGEOUS EFFECTS OF INVENTION

**[0022]** According to the present invention, a steel sheet manufactured with the above-mentioned component steel satisfies the correlation  $HER(\%) = -51 + 0.209[TS(\text{MPa})] - 143[S(\%)] - 42.6\%[Cr+Ni+Cu(\%)] + 8.22[MnS \text{ aspect ratio}] - 27.5[MnS \text{ fraction}] - 43.7[MnS \text{ size}]$ , has a tensile strength of 590 MPa or more, a uniform elongation of 18% or more, and a hole expansion ratio (HER) of 40% or more. Furthermore, a high-strength thin steel sheet, in which the difference between the (Ni+Cu) content at a thickness position 0.1 μm directly below the surface layer and the (Ni+Cu) content at a thickness position 50 μm from the surface layer is 0.1% or more, can be economically manufactured using conventional annealing equipment and can be used for automotive body inner panels and structural components.

#### BRIEF DESCRIPTION OF DRAWINGS

**[0023]**

FIG. 1 is a photograph showing the distribution of MnS inclusions in a cross-section of a steel sheet of Inventive Example 3 in an embodiment of the present invention.

FIG. 2 is a photograph showing the distribution of MnS inclusions in a cross-section of a steel sheet of Comparative Example 4 in an embodiment of the present invention.

FIG. 3 is a graph showing the enrichment amount of (Ni+Cu) on the surface layer of the steel sheets of Inventive Example 2 and Comparative Example 4 in an embodiment of the present invention.

#### BEST MODE FOR THE INVENTION

**[0024]** Hereinafter, the present invention will be described.

**[0025]** The present invention relates to a steel sheet applicable to automotive body inner panels and structural components by a cold forming method, wherein the difference between the (Ni+Cu) content at a position 0.1 μm directly below the thickness and the (Ni+Cu) content at a position 50 μm from the surface layer is 0.1% or more. It is characterized by providing a cold-rolled steel sheet, a hot-dip galvanized steel sheet, and a galvanized steel sheet having a uniform elongation of 18% or more and a hole expansion ratio of 40% or more, even in a steel sheet having a sulfur (S) content of 0.07% or less.

**[0026]** The cold-rolled steel sheet of the present invention may comprise, by weight %, C: 0.06 to 0.09%, Mn: 1.2 to

1.6%, Si: 1.3 to 1.7%, P: 0.02% or less, S: 0.007% or less, Al: 0.05% or less, Cr: 0.2% or less (including 0%), Ni: 0.2% or less (including 0%), Cu: 0.3% or less (including 0%), Ti: 0.02% or less (including 0%), Ca: 0.0040% or less (including 0%), N: 0.01% or less, and a sum of Cr+Ni+Cu content of 0.7% or less, with the remainder being Fe and other impurities, and may satisfy Relational Expression 1.

**[0027]** Hereinafter, the steel component composition of the present invention will be described, and "%" means % by weight unless otherwise specified.

C: 0.06 to 0.09%

**[0028]** Carbon (C) is an element necessary for increasing the strength of steel and securing the fraction of retained austenite phase. Specifically, it is dissolved in the austenite phase during continuous annealing and subsequent cooling processes. When the steel sheet is isothermally heat-treated at a temperature where the bainite phase is formed, it is dissolved within the austenite phase, thereby reducing the transformation temperature of the martensite phase to room temperature or below. However, if the content is less than 0.06%, it is difficult to secure a tensile strength of 590 MPa or more for the steel, or to secure a fraction of the retained austenite phase of less than 5%. On the other hand, if the carbon (C) content exceeds 0.09%, the fraction of the martensite phase increases excessively, making it difficult to secure a uniform elongation of 18% or more.

**[0029]** Therefore, in the present invention, it is preferable to limit the carbon (C) content to 0.06 to 0.09%. More preferably, it is limited to 0.07 to 0.08%.

Mn: 1.2 to 1.6%

**[0030]** Manganese (Mn) is an element that suppresses the formation of the ferrite phase and increases the stability of the austenite phase. As the manganese (Mn) content increases, the transformation temperatures of the bainite and martensite phases are lowered. In particular, during the subsequent cooling heat treatment process after isothermal transformation of the steel, the austenite phase can transform into the martensite phase, which may reduce the fraction of the retained austenite phase in the final microstructure, thereby decreasing the ductility of the steel. If the content is less than 1.2%, it is difficult to secure sufficient strength of the steel, whereas if the content exceeds 1.6%, it is difficult to secure the cold formability including the target uniform elongation or hole expansion ratio. Therefore, in the present invention, it is preferable to limit the manganese (Mn) content to 1.2 to 1.6%. More preferably, it is limited to 1.3 to 1.5%.

Si: 1.3 to 1.7%

**[0031]** Silicon (Si) is an element that increases strength through solid solution strengthening of steel or suppresses the formation of iron carbides during the transformation process of constituent phases. During isothermal heat treatment of steel, as a portion of the austenite phase transforms into bainite, excess carbon (C) can diffuse into the austenite phase or form iron carbides. Therefore, when the silicon (Si) content is appropriately controlled, the formation of iron carbides can be suppressed, thereby increasing the stability of the austenite phase. If the silicon content is less than 1.3%, iron carbides may form during isothermal holding, isothermal transformation heat treatment, or reheating and overaging heat treatment, which can reduce the fraction of retained austenite in the final microstructure. On the other hand, if the content exceeds 1.7%, excessive formation of silicon (Si)-manganese (Mn) composite oxides on the steel sheet can lead to poor plating properties. Therefore, in the present invention, it is preferable to limit the silicon (Si) content to 1.3 to 1.7%. More preferably, it is limited to 1.4 to 1.6%.

P: 0.02% or less (excluding 0%)

**[0032]** Phosphorus (P) is an element that increases the strength of steel. If its content exceeds 0.02%, the weldability of the steel may be reduced. On the other hand, controlling the P content to be excessively low requires a dephosphorization treatment with the addition of quicklime (CaO), which can lead to an increase in the cost of the steelmaking process. Therefore, it is preferable to limit the phosphorus (P) content to 0.02% or less. More preferably, it is limited to 0.01% or less.

S: 0.007% or less (excluding 0%)

**[0033]** Sulfur (S) can segregate as MnS non-metallic inclusions within the steel or during continuous casting solidification, causing hot cracking. In addition, if MnS inclusions are excessively present in the steel, it can lower the hole expansion ratio (HER) of the steel, leading to a sharp decrease in cold formability. On the other hand, if the sulfur

content is excessively low, it can lead to an increase in steelmaking costs. Therefore, in the present invention, it is preferable to limit the sulfur (S) content to 0.007% or less. More preferably, it is limited to 0.003% or less.

Al: 0.05% or less (excluding 0%)

**[0034]** Aluminum (Al) is an element added as a deoxidizer. Aluminum (Al) can react with nitrogen (N) in the steel to form AlN precipitates, which can cause cracks in the slab during the continuous casting process. In addition, aluminum (Al) reacts with oxygen in the steel and exists as an oxide inclusion, in which case it can act as a nucleation site for MnS inclusions, making the MnS size finer or causing it to be distributed relatively uniformly. If its content is excessively added, it can form a large amount of hard oxides such as Al<sub>2</sub>O<sub>3</sub>, thereby reducing the toughness of the steel. Therefore, the aluminum (Al) content is limited to 0.05% or less (excluding 0%). More preferably, it is limited to 0.03%.

Cr: 0.2% or less (including 0%)

**[0035]** Chromium (Cr) is an element that increases the strength of steel by suppressing the transformation of ferrite and bainite. In addition, chromium forms a manganese-chromium composite oxide on the surface of the steel, which increases wettability and platability during hot-dip galvanizing after annealing. However, if its content exceeds 0.2%, it increases the strength of the steel of the present invention, making it difficult to achieve the target uniform elongation. Furthermore, chromium can be enriched at specific locations, such as ferrite grain boundaries, forming a chromium depletion region in the adjacent area, which can cause pitting corrosion. Therefore, it is preferable to limit the chromium (Cr) content to 0.2% or less (including 0%).

Ni: 0.2% or less (including 0%)

**[0036]** Nickel (Ni) is an element that increases the stability of the austenite phase. Nickel (Ni) is effective in suppressing high-temperature embrittlement, but if its content exceeds 0.2%, there is a problem of increased manufacturing cost of the steel. Therefore, in the present invention, it is preferable to limit the nickel content to 0.2% or less.

Cu: 0.3% or less (including 0%)

**[0037]** Copper (Cu) is an element that increases the stability of the austenite phase. While copper (Cu) is effective in increasing corrosion resistance, it can become enriched on the surface of the slab and cause surface cracks, so it is preferable to use it together with nickel (Ni) rather than alone. Furthermore, in the present invention, it is understood that it reacts with sulfur (S) in the steel to form fine CuS precipitates, which has the effect of refining relatively coarse MnS inclusions or dispersing them uniformly. It is also understood that while it decreases the fraction of the austenite phase in the final microstructure, it increases the carbon (C) solid solution content. However, if its content exceeds 0.3%, it can lead to an increase in strength and a decrease in ductility due to solid solution strengthening. Therefore, in the present invention, it is preferable to limit the copper content to 0.3% or less.

Ti: 0.02% or less (including 0%)

**[0038]** Titanium (Ti) is an element that forms precipitates including carbides or nitrides. If its content exceeds 0.02%, coarse TiN precipitates may remain in the steel and form microcracks at the interface of matrix iron, which can lead to a decrease in the hole expansion ratio of the steel. On the other hand, in the present invention, TiN nitrides formed in the steel can react with sulfur (S) to form TiS sulfides, which can uniformly disperse MnS inclusions, thereby having a positive effect on the hole expansion ratio of the steel. However, if its content exceeds 0.02%, it can refine the crystal grains of the steel, leading to an increase in yield strength or a decrease in ductility. Therefore, in the present invention, it is preferable to limit the titanium content to 0.02% or less.

Ca: 0.0040% or less (including 0%)

**[0039]** Calcium (Ca) is an element that controls the shape of MnS inclusions. However, if its content exceeds 0.0040%, there is a limit to improving the hole expansion ratio of the steel sheet by changing the shape of the inclusions from a stringy form to a spherical form. Therefore, in the present invention, it is preferable to limit the calcium content to 0.0040% or less.

N: 0.01% or less

**[0040]** Nitrogen (N) is an element that forms nitrides or increases the stability of the austenite phase. As the nitrogen content in the steel increases, the number density of AlN and TiN nitrides increases, which deteriorates the cold formability of the steel. Therefore, in the present invention, it is preferable to limit the nitrogen content to 0.02% or less.

**[0041]** Meanwhile, in addition to the components described above, the steel sheet of the present invention may contain one or more of boron (B) or antimony (Sb) elements to secure the strength of the steel sheet or improve the surface hardness.

B: 0.005% or less

**[0042]** Boron (B) is an element that increases the hardenability of steel. When added in an appropriate amount, it suppresses the formation of the ferrite phase and increases hardenability, but excessive addition can raise the austenite recrystallization temperature or increase brittleness through a decrease in elongation. Therefore, in the present invention, it is preferable to limit its content to 0.005% or less.

Sb: 0.03% or less

**[0043]** Antimony (Sb) is an element that suppresses decarburization on the surface of steel. When added in an appropriate amount, it becomes enriched on the surface of the steel sheet to suppress decarburization or can suppress the formation of oxides of manganese, silicon, and aluminum on the steel sheet surface during annealing. If its content exceeds 0.03%, the effect is saturated or the manufacturing cost increases. Therefore, in the present invention, it is preferable to limit the antimony content to 0.03% or less.

**[0044]** In the present invention, the remainder, other than the components described above, is composed of Fe and other impurities.

Relational Expression 1

**[0045]** In the present invention, the contents of chromium (Cr), nickel (Ni), and copper (Cu) must satisfy the following Relational Expression 1.

[Relational Expression 1]

$$0.08 \leq (\text{Cr} + \text{Ni} + \text{Cu}) / (\text{C} + \text{Mn}) \leq 0.7 \quad (\text{by weight})$$

**[0046]** The  $(\text{Cr} + \text{Ni} + \text{Cu}) / (\text{C} + \text{Mn})$  ratio is a necessary condition for securing the cold formability of the steel. In particular, it is necessary to secure sufficient ductility, including a tensile strength of 590 MPa or more and a uniform elongation of 18% or more. When the contents of chromium (Cr), nickel (Ni), and copper (Cu) are high, the bainite transformation is delayed during isothermal transformation holding or heating in the annealing process of the steel sheet, and carbon (C) diffusion within the austenite is restricted or the chemical stability of retained austenite is reduced, which decreases the fraction of the retained austenite phase and increases the fraction of the martensite phase in the final microstructure. As a result, the tensile strength of the steel is increased or the elongation is decreased.

**[0047]** On the other hand, it is understood that carbon (C) or manganese (Mn) elements increase the fraction of the retained austenite phase, thereby increasing elongation. Therefore, as a method for securing a tensile strength of 590 MPa or more and a uniform elongation of 18% or more, the present invention limits the  $(\text{Cr} + \text{Ni} + \text{Cu}) / (\text{C} + \text{Mn})$  ratio to a range of 0.08 to 0.7.

Relational Expression 2

**[0048]**

[Relational Expression 2]

$$0.06 \leq (\text{Al} + \text{Cu} + \text{Ti} + \text{Ca}) / (\text{Mn} + \text{S}) \leq 0.5 \quad (\text{by weight})$$

**[0049]** In the present invention, the  $(\text{Al} + \text{Cu} + \text{Ti} + \text{Ca}) / (\text{Mn} + \text{S})$  ratio is a preferable condition for securing the hole

expansion ratio of the steel by changing the size or distribution pattern of MnS inclusions in the steel sheet.

[0050] Specifically, it is a preferable condition for securing a hole expansion ratio of 40% or more. In the present invention, it was confirmed that when the sulfur (S) content increases, the distribution and area fraction of MnS inclusions vary. It was experimentally confirmed that if its content exceeds 0.5%, the MnS inclusions present in the steel sheet cluster together, or the area occupied by MnS inclusions based on the total area of the steel sheet increases sharply, causing the hole expansion ratio of the steel sheet to decrease to half its level. On the other hand, when the contents of aluminum (Al), copper (Cu), titanium (Ti), and calcium (Ca) are appropriately controlled, it was confirmed that MnS inclusions are partially dispersed by Al<sub>2</sub>O<sub>3</sub>, TiN, etc., or that CuS sulfides precipitate finely (not confirmed at the magnification of a scanning electron microscope, but present in the matrix at the magnification of a transmission electron microscope), resulting in a relative decrease in the area fraction. As a result, a hole expansion ratio of 40% or more could be secured for the steel. Therefore, as a method for improving the hole expansion ratio of the steel, it is preferable to limit the (Al+Cu+Ti+Ca)/(Mn+S) ratio to a range of 0.06 to 0.5.

Relational Expression 3

[0051]

[Relational Expression 3]

$$(\text{Ni}+\text{Cu}) \text{ at } 0.1\mu\text{m} - (\text{Ni}+\text{Cu}) \text{ at } 50\mu\text{m} \geq 0.1\% \text{ (by weight)}$$

[0052] In the present invention, the difference between the (Ni+Cu) content at a thickness position 0.1 μm directly below the surface layer of the steel sheet and the (Ni+Cu) content at a thickness position 50 μm from the surface layer can satisfy the above Relational Expression 3. That is, the value of (Ni+Cu) at 0.1 μm - (Ni+Cu) at 50 μm is a necessary condition for limiting the size of the surface enrichment of the steel to an appropriate level. Failure to satisfy Relational Expression 3 means that nickel (Ni) or copper (Cu) elements are uniformly distributed in the steel. On the other hand, when these elements are enriched on the surface of the steel sheet, the occurrence of decarburization on the surface of the steel sheet can be suppressed, thereby compensating for the decrease in surface hardness. Therefore, as a method for minimizing the decrease in surface hardness, it is preferable to control the value of (Ni+Cu) at 0.1 μm - (Ni+Cu) at 50 μm to 0.1% or more.

[0053] Meanwhile, the steel sheet of the present invention may have a mixed microstructure of ferrite, retained austenite, and bainite + martensite, and it is preferable that the sum of the fractions of the bainite and martensite phases is 9 area% or less. And, it is preferable that the fraction of retained austenite is 5% or less. If the sum of the fractions of the bainite and martensite phases exceeds 9 area%, the amounts of Cr, Cu, and Ni added increase, and accordingly, the fraction of the retained austenite structure decreases and the fraction of martensite increases, which increases the tensile strength but lowers the yield strength, making it difficult to secure desired properties. And if the fraction of retained austenite exceeds 5 area%, the amounts of C and Mn added increase, which increases the strength of the steel but may worsen the hole expansion property.

[0054] As described above, the steel sheet of the present invention having the steel composition and microstructure can have a tensile strength of 590 MPa or more, a uniform elongation of 18% or more, and a hole expansion ratio (HER) of 40% or more.

[0055] Next, a method for manufacturing a steel sheet of the present invention will be described.

[0056] The present invention manufactures a slab by melting a steel sheet that satisfies the above-mentioned composition components and Relational Expression 1. As a melting method, a blast furnace or electric furnace steelmaking method can be selectively used.

[0057] The method for manufacturing a steel sheet of the present invention comprises the steps of: heating a steel slab satisfying the above-mentioned composition components and Relational Expression 1 to a temperature range of 1150 to 1300°C; obtaining a hot-rolled steel sheet by finish hot-rolling the heated steel slab in a temperature range of 800 to 1000°C; cooling the hot-rolled steel sheet and coiling it at a temperature of 510 to 620°C; cold-rolling the coiled steel sheet at a cold reduction ratio of 30 to 70%; and heating the cold-rolled steel sheet to a temperature of 780 to 820°C, followed by a first slow cooling to 600 to 700°C, and then a second rapid cooling to a temperature range of 350 to 450°C at an average cooling rate of 10°C/sec or more, and then holding for 100 to 700 seconds.

[0058] First, in the present invention, a steel slab satisfying the above-mentioned composition components and Relational Expression 1 is heated to a temperature range of 1150 to 1300°C. If the heating temperature is less than 1150°C, it is difficult to secure the rolling temperature of the steel sheet during the hot rolling process, and there is a problem of increased rolling load. On the other hand, if the reheating temperature exceeds 1300°C, there is a problem in that a large amount of scale is generated on the surface of the slab or bar plate. Therefore, in the present invention,

it is preferable to control the slab reheating temperature in the range of 1150 to 1300°C.

**[0059]** Furthermore, in the present invention, the steel slab may satisfy the above-mentioned Relational Expression 2.

**[0060]** Subsequently, in the present invention, a hot-rolled steel sheet is manufactured by finish hot-rolling the reheated steel slab in a temperature range of 800 to 1000°C. At this time, the finish hot rolling is performed at a temperature of Ar3 or higher, which is a normal condition, and specifically, it is preferably performed in a temperature range of 800 to 1000°C. If the finish hot rolling temperature is less than 800°C, the rolling load increases significantly, and if it exceeds 1000°C, there is a problem in that the thermal fatigue of the rolling rolls increases significantly. Therefore, in the present invention, the finish hot rolling temperature is set to 800 to 1000°C.

**[0061]** And in the present invention, the manufactured hot-rolled steel sheet is cooled on a run-out table and coiled at a temperature of 510 to 620°C. If the coiling temperature is less than 510°C, martensite and bainite may be excessively formed in the hot-rolled steel sheet, which may increase the rolling load during subsequent cold rolling. On the other hand, if the coiling temperature exceeds 620°C, decarburization may occur on the surface layer or excessive scale may be generated, so that iron-scale may exist despite the descaling operation, which may deteriorate the platability of the final plated steel sheet.

**[0062]** Subsequently, the coiled hot-rolled steel sheet may be pickled by a conventional method to remove the surface oxide layer.

**[0063]** Subsequently, in the present invention, the coiled steel sheet is cold-rolled at a cold reduction ratio of 30 to 70% to produce a cold-rolled steel sheet with a target thickness. The cold reduction ratio during cold rolling can be in the range of 30 to 70%. If the cold reduction ratio is less than 30%, the cumulative reduction amount may be insufficient, leading to incomplete austenite recrystallization during continuous annealing. On the other hand, if the cold reduction ratio exceeds 70%, austenite recrystallization may be excessive, leading to the formation of coarse austenite or ferrite grains during continuous annealing. Therefore, in the present invention, it is preferable to control the cold reduction ratio in the range of 30 to 70%.

**[0064]** Subsequently, in the present invention, the cold-rolled steel sheet is subjected to continuous annealing heat treatment. This continuous annealing heat treatment process secures a steel sheet microstructure composed of appropriate fractions of ferrite, bainite, martensite, and retained austenite, thereby providing a steel sheet with excellent cold formability, having a tensile strength of 590 MPa or more and a uniform elongation of 18% or more, which is a very important process.

**[0065]** Specifically, in the present invention, the cold-rolled steel sheet is heated to a temperature of 780 to 820°C, followed by a first slow cooling to 600 to 700°C, and then a second rapid cooling to a temperature range of 350 to 450°C at an average cooling rate of 10°C/sec or more, followed by isothermal transformation holding for 100 to 700 seconds.

**[0066]** First, in the present invention, the cold-rolled steel sheet is heated to an annealing temperature of 780 to 820°C.

**[0067]** If the annealing temperature is less than 780°C, the austenite fraction is insufficient, making it difficult to secure the target strength. On the other hand, if it exceeds 820°C, the austenite fraction is sufficient, but coarse crystal grains are formed, which can lead to a decrease in austenite stability and a decrease in the retained austenite fraction during the subsequent cooling process, resulting in a decrease in elongation. Therefore, in the present invention, it is preferable to control the annealing temperature to 780 to 820°C.

**[0068]** Subsequently, in the present invention, the heated cold-rolled steel sheet is subjected to a first slow cooling to 600 to 700°C. The present invention is not particularly limited to the first slow cooling temperature, but the slow cooling temperature is controlled in the range of 600 to 700°C in consideration of the characteristics of an actual annealing line. And, the slow cooling rate at this time is not limited, and for example, a slow cooling of 2°C/s can be used.

**[0069]** And in the present invention, the first slowly cooled steel sheet is rapidly cooled for a second time to a temperature range of 350 to 450°C at an average cooling rate of 10°C/sec or more.

**[0070]** In the present invention, it is preferable to control the second rapid cooling stop temperature in the range of 350 to 450°C. If the second rapid cooling stop temperature is less than 350°C, it is close to the Ms temperature of the steel sheet, making it difficult to promote bainite transformation without additional reheating, and thus difficult to secure a sufficient fraction of retained austenite. On the other hand, if the rapid cooling stop temperature exceeds 450°C, the possibility of carbide formation increases, which can reduce the carbon (C) content diffusing into the austenite phase or also reduce the fraction of the retained austenite phase. Therefore, in the present invention, it is preferable to control the second rapid cooling stop temperature to 350 to 450°C.

**[0071]** In addition, it is preferable to control the average cooling rate during this second cooling to 8°C/sec or more. If the cooling rate is less than 8°C/sec, new ferrite or pearlite phases may be excessively formed during the cooling process, which can reduce the austenite fraction that should be involved in the bainite transformation.

**[0072]** Subsequently, in the present invention, the second rapidly cooled cold-rolled steel sheet is held for 100 to 700 seconds. If the holding time is less than 100 seconds, carbon diffusion that can increase the stability of retained

austenite may occur insufficiently, while if the holding time exceeds 700 seconds, there is a problem of decreased steel sheet manufacturing productivity. Therefore, in the present invention, it is preferable to control the holding time in the range of 100 to 700 seconds.

**[0073]** By using the manufacturing process as described above, a cold-rolled steel sheet with a (Ni+Cu) at 0.1 $\mu$ m - (Ni+Cu) at 50 $\mu$ m value controlled to 0.1% or more can be obtained, and furthermore, a cold-rolled steel sheet having a tensile strength of 590 MPa or more, a uniform elongation of 18% or more, and a hole expansion ratio (HER) of 40% or more can be obtained.

**[0074]** Meanwhile, in the present invention, if necessary, a hot-dip galvanized steel sheet can be manufactured by heating the maintained cold-rolled steel sheet to a temperature of 400 to 470°C and then using a conventional method.

**[0075]** Furthermore, in the present invention, a galvanized steel sheet can also be manufactured by heating the hot-dip galvanized steel sheet to a temperature of 500 to 560°C and then performing an alloying heat treatment.

**[0076]** In addition, in the present invention, skin pass rolling can be performed on the manufactured cold-rolled steel sheet, hot-dip galvanized steel sheet, or galvanized steel sheet for the purpose of shape correction or surface roughness control, and since excessive skin pass rolling can deteriorate the ductility of the heat-treated steel sheet, it is preferable to perform the skin pass rolling within an elongation range of 0.1 to 1.5%.

#### MODE FOR THE INVENTION

**[0077]** Hereinafter, the present invention will be described in detail through examples

(Example)

[0078]

[Table 1]

| Category      | C     | Si   | Mn   | P      | S      | S.Al  | Cr    | Ni    | Ti    | Cu    | N      | Ca     | Eq. 1 | Eq. 2 | Eq. 3 |
|---------------|-------|------|------|--------|--------|-------|-------|-------|-------|-------|--------|--------|-------|-------|-------|
| Inv. Steel 1  | 0.076 | 1.46 | 1.47 | 0.0090 | 0.0030 | 0.03  | 0.040 | 0.024 | 0     | 0.069 | 0.0060 | 0.0006 | 0.09  | 0.068 | 1.88  |
| Inv. Steel 2  | 0.080 | 1.47 | 1.45 | 0.0090 | 0.0060 | 0.03  | 0.039 | 0.026 | 0.002 | 0.066 | 0.0060 | 0.0005 | 0.09  | 0.068 | 0.10  |
| Inv. Steel 3  | 0.088 | 1.43 | 1.46 | 0.0090 | 0.0020 | 0.03  | 0.173 | 0.123 | 0.002 | 0.392 | 0.0064 | 0.0010 | 0.44  | 0.291 | 0.10  |
| Inv. Steel 4  | 0.090 | 1.48 | 1.47 | 0.0090 | 0.0070 | 0.03  | 0.177 | 0.126 | 0.002 | 0.393 | 0.0072 | 0.0006 | 0.45  | 0.288 | 0.10  |
| Inv. Steel 5  | 0.088 | 1.46 | 1.45 | 0.0090 | 0.0020 | 0.03  | 0.106 | 0.073 | 0.002 | 0.230 | 0.0060 | 0.0005 | 0.27  | 0.181 | 0.10  |
| Inv. Steel 6  | 0.086 | 1.47 | 1.44 | 0.0100 | 0.0070 | 0.03  | 0.102 | 0.074 | 0.002 | 0.232 | 0.0055 | 0.0005 | 0.27  | 0.183 | 0.10  |
| Comp. Steel 1 | 0.087 | 1.46 | 1.44 | 0.0090 | 0.0120 | 0.03  | 0.039 | 0.025 | 0.002 | 0.067 | 0.0057 | 0.0004 | 0.09  | 0.068 | 0.06  |
| Comp. Steel 2 | 0.087 | 1.46 | 1.46 | 0.0090 | 0.0020 | 0.03  | 0.341 | 0.241 | 0.002 | 0.746 | 0.0060 | 0.0004 | 0.86  | 0.532 | 0.18  |
| Comp. Steel 3 | 0.089 | 1.50 | 1.49 | 0.0090 | 0.0060 | 0.03  | 0.347 | 0.247 | 0.002 | 0.772 | 0.0062 | 0.0007 | 0.87  | 0.538 | 0.17  |
| Comp. Steel 4 | 0.089 | 1.49 | 1.49 | 0.0090 | 0.0110 | 0.03  | 0.349 | 0.246 | 0.002 | 0.769 | 0.0064 | 0.0006 | 0.86  | 0.534 | 0.09  |
| Comp. Steel 5 | 0.087 | 1.44 | 1.44 | 0.0090 | 0.0120 | 0.03  | 0.170 | 0.120 | 0.002 | 0.382 | 0.0067 | 0.0004 | 0.44  | 0.285 | 0.10  |
| Comp. Steel 6 | 0.085 | 1.49 | 1.44 | 0.080  | 0.0110 | 0.03  | 0.108 | 0.073 | 0.002 | 0.229 | 0.0054 | 0.0003 | 0.27  | 0.180 | 0.10  |
| Inv. Steel 7  | 0.05  | 1.50 | 1.47 | 0.009  | 0.0010 | 0.012 | 0.05  | 0.100 | 0.025 | 0.050 | 0.006  | 0      | 0.132 | 0.060 | 0.11  |
| Inv. Steel 8  | 0.08  | 1.5  | 1.22 | 0.009  | 0.0010 | 0.015 | 0.10  | 0.001 | 0.001 | 0.150 | 0.005  | 0.004  | 0.193 | 0.136 | 0.12  |
| Inv. Steel 9  | 0.08  | 1.2  | 1.45 | 0.009  | 0.0060 | 0.03  | 0.175 | 0.122 | 0.010 | 0.245 | 0.0069 | 0.0005 | 0.354 | 0.196 | 0.10  |
| Inv. Steel 10 | 0.063 | 1.20 | 1.45 | 0.009  | 0.0060 | 0.03  | 0.142 | 0.122 | 0.010 | 0.243 | 0.0069 | 0.0005 | 0.335 | 0.195 | 0.10  |

[Table 2]

| Category    | Rolling Temp. (°C) | Coiling Temp. (°C) | Speed (mpm) | Annealing (°C) | 1st Cooling (°C) | Rapid Cooling (°C) | Holding/ Heating (°C) | GI Plating (°C) | GI Cooling (°C) | GA Temp. (°C) | GA Cooling (°C) | Remarks       |
|-------------|--------------------|--------------------|-------------|----------------|------------------|--------------------|-----------------------|-----------------|-----------------|---------------|-----------------|---------------|
| Inv. Ex. 1  | 910                | 524                | 90          | 801            | 639              | 399                | 400/440               | 460             | -               | 510           | 280             | Inv. Steel 1  |
| Inv. Ex. 2  | 908                | 508                | 90          | 799            | 639              | 400                | 400/420               | 460             | -               | 507           | 280             | Inv. Steel 2  |
| Inv. Ex. 3  | 909                | 508                | 90          | 787            | 637              | 364                | 364/400               | 460             | -               | 510           | 280             | Inv. Steel 3  |
| Inv. Ex. 4  | 910                | 554                | 90          | 797            | 639              | 398                | 398/400               | 460             | -               | 510           | 280             | Inv. Steel 4  |
| Inv. Ex. 5  | 906                | 513                | 90          | 800            | 640              | 399                | 399/400               | 460             | 280             | 506           | 280             | Inv. Steel 5  |
| Inv. Ex. 6  | 918                | 522                | 90          | 801            | 640              | 400                | 400/400               | 460             | 280             | 510           | 280             | Inv. Steel 6  |
| Comp. Ex. 1 | 909                | 527                | 90          | 803            | 639              | 399                | 400/400               | 460             | 280             | 510           | 280             | Comp. Steel 1 |
| Comp. Ex. 2 | 909                | 519                | 90          | 820            | 640              | 400                | 400/400               | 460             | 280             | 510           | 280             | Comp. Steel 2 |
| Comp. Ex. 3 | 900                | 580                | 90          | 800            | 640              | 407                | 407/400               | 460             | 280             | 510           | 280             | Comp. Steel 3 |
| Comp. Ex. 4 | 914                | 553                | 90          | 802            | 638              | 405                | 405/400               | 460             | 280             | 510           | 280             | Comp. Steel 4 |
| Comp. Ex. 5 | 900                | 580                | 90          | 803            | 640              | 400                | 399/400               | 460             | 280             | 510           | 280             | Comp. Steel 5 |
| Comp. Ex. 6 | 900                | 580                | 90          | 800            | 640              | 400                | 400/400               | 460             | 280             | 510           | 280             | Comp. Steel 6 |
| Comp. Ex. 7 | 921                | 600                | 90          | 770            | 650              | 324                | 400/450               | 460             | -               | 510           | 280             | Inv. Steel 5  |
| Comp. Ex. 8 | 922                | 530                | 120         | 850            | 650              | 324                | 400/450               | 460             | -               | 510           | 280             | Inv. Steel 6  |
| Inv. Ex. 7  | 921                | 530                | 90          | 830            | 650              | 324                | 400                   | -               | 150             | -             | -               | Inv. Steel 7  |
| Inv. Ex. 8  | 903                | 510                | 112         | 799            | 639              | 398                | 400                   | -               | 150             | -             | -               | Inv. Steel 8  |
| Inv. Ex. 9  | 912                | 543                | 95          | 802            | 638              | 399                | 400/451               | 460             | 280             | -             | -               | Inv. Steel 9  |
| Inv. Ex. 10 | 913                | 541                | 102         | 804            | 638              | 399                | 400/473               | 460             | 280             | -             | -               | Inv. Steel 10 |

**[0079]** Using steel slabs having the compositions as shown in Table 1, hot rolling, continuous annealing, and hot-dip galvanizing or galvannealing heat treatment were performed under the conditions of Table 2 to manufacture cold-rolled steel sheets and plated steel sheets with a thickness of 1.2 mm. Specifically, the as-produced slabs or lab-made ingots prepared before hot rolling were heated in a range of  $1200 \pm 20^\circ\text{C}$  for 60 minutes for homogenization treatment. Subsequently, individual slabs or ingots were subjected to rough rolling and finish rolling and coiled at a temperature of  $510$  to  $580^\circ\text{C}$  to produce hot-rolled steel sheets with a thickness of 2.4 mm. After applying a 50% cold reduction ratio to produce cold-rolled steel sheets, continuous annealing heat treatment or plating heat treatment was performed to manufacture cold-rolled steel sheets or plated steel sheets. In Table 1, Inventive Steels (1-10) satisfy Relational Expressions 1-3, whereas Comparative Steels 1-6 fail to satisfy at least one of Relational Expressions 1-3. Table 2 shows the specific hot rolling temperature, coiling temperature, and continuous annealing or hot-dip plating heat treatment conditions applied to the inventive and comparative steels. At this time, the second cooling rate was uniformly set to  $10^\circ\text{C/s}$ .

**[0080]** For the cold-rolled steel sheets and plated steel sheets manufactured as described above, the results of measuring the fraction of constituent phases in the microstructure, the carbon solid solution content in the retained austenite phase, the fraction of MnS inclusions, the tensile properties, and the hole expansion ratio (HER) are shown in Table 3 below.

**[0081]** The microstructure of the steel sheet was observed with a scanning electron microscope at a position of  $1/4$  of the thickness of the steel sheet, and the results were quantitatively evaluated using an image analyzer, and the results are shown in Table 3 below. In addition, the fraction of the retained austenite phase was measured using an X-ray diffraction analyzer, and the carbon solid solution content in the retained austenite phase was calculated using a commonly known empirical formula. Meanwhile, in Table 3 below, the remaining structure of the cold-rolled steel sheet and the plated steel sheet is ferrite.

**[0082]** In addition, the fraction of MnS inclusions was quantitatively analyzed by capturing six or more images of the cross-section of the steel slab at a magnification of X500 with an optical microscope and using an image analyzer.

**[0083]** And the tensile properties were evaluated after shearing a specimen in a direction perpendicular to the rolling direction, processing it according to JIS standards, and heat-treating it. The hole expansion ratio (HER) was measured according to VDA standards.

[Table 3]

| Category    | Aret (%) | Aret[ C] | B+M (%) | MnS Area Fraction (%) | Yield Strength (MPa) | Tensile Strength (MPa) | Total Elongation (%) | Uniform Elongation (%) | Hole Expansion Ratio (%) | Remarks       |
|-------------|----------|----------|---------|-----------------------|----------------------|------------------------|----------------------|------------------------|--------------------------|---------------|
| Inv. Ex. 1  | 3.2      | 1.26     | 7.6     | 0.05                  | 392                  | 607                    | 33.4                 | 20.9                   | 67.2                     | Inv. Steel 1  |
| Inv. Ex. 2  | 2.5      | 1.31     | 6.4     | 0.09                  | 406                  | 610                    | 30.7                 | 19.4                   | 42.1                     | Inv. Steel 2  |
| Inv. Ex. 3  | 2.0      | 1.40     | 8.2     | 0.09                  | 387                  | 655                    | 28.9                 | 18.9                   | 40.2                     | Inv. Steel 3  |
| Inv. Ex. 4  | 2.1      | 1.43     | 8.5     | 0.10                  | 390                  | 665                    | 30.9                 | 18.3                   | 44.5                     | Inv. Steel 4  |
| Inv. Ex. 5  | 4.2      | 1.17     | 7.5     | 0.03                  | 391                  | 632                    | 35.0                 | 19.9                   | 48.3                     | Inv. Steel 5  |
| Inv. Ex. 6  | 3.4      | 1.35     | 7.8     | 0.10                  | 393                  | 625                    | 32.8                 | 20.5                   | 51.0                     | Inv. Steel 6  |
| Comp. Ex. 1 | 2.9      | 1.32     | 7.5     | 0.15                  | 397                  | 644                    | 31.8                 | 19.5                   | 40.8                     | Comp. Steel 1 |
| Comp. Ex. 2 | 2.4      | 1.35     | 6.2     | 0.14                  | 403                  | 617                    | 33.6                 | 19.9                   | 42.3                     | Comp. Steel 2 |
| Comp. Ex. 3 | 2.9      | 1.48     | 9.3     | 0.02                  | 328                  | 726                    | 26.0                 | 15.9                   | 38.4                     | Comp. Steel 3 |
| Comp. Ex. 4 | 2.6      | 1.51     | 10.2    | 0.11                  | 326                  | 733                    | 27.2                 | 15.4                   | 37.8                     | Comp. Steel 4 |

(continued)

| Category                                                                                                                                                        | Aret (%) | Aret[ C] | B+M (%) | MnS Area Fraction (%) | Yield Strength (MPa) | Tensile Strength (MPa) | Total Elongation (%) | Uniform Elongation (%) | Hole Expansion Ratio (%) | Remarks       |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|----------|---------|-----------------------|----------------------|------------------------|----------------------|------------------------|--------------------------|---------------|
| Comp. Ex. 5                                                                                                                                                     | 2.1      | 1.48     | 10.7    | 0.13                  | 339                  | 742                    | 24.7                 | 15.4                   | 37.4                     | Comp. Steel 5 |
| Comp. Ex. 6                                                                                                                                                     | 3.6      | 1.26     | 7.8     | 0.13                  | 393                  | 617                    | 31.2                 | 19.5                   | 47.7                     | Comp. Steel 6 |
| Comp. Ex. 7                                                                                                                                                     | 3.4      | 1.32     | 7.9     | 0.03                  | 343                  | 595                    | 32.2                 | 19.6                   | 51.1                     | Inv. Steel 5  |
| Comp. Ex. 8                                                                                                                                                     | 4.2      | 1.23     | 8.6     | 0.11                  | 376                  | 692                    | 27.3                 | 17.5                   | 39.4                     | Inv. Steel    |
| Inv. Ex. 7                                                                                                                                                      | 3.0      | 1.29     | 7.6     | 0.06                  | 338                  | 521                    | 38.7                 | 23.2                   | 55.2                     | Inv. Steel 7  |
| Inv. Ex. 8                                                                                                                                                      | 3.0      | 1.30     | 7.7     | 0.05                  | 421                  | 687                    | 29.5                 | 18.0                   | 54.1                     | Inv. Steel 8  |
| Inv. Ex. 9                                                                                                                                                      | 2.9      | 1.34     | 8.0     | 0.08                  | 410                  | 679                    | 28.2                 | 17.3                   | 47.6                     | Inv. Steel 8  |
| Inv. Ex. 10                                                                                                                                                     | 2.9      | 1.34     | 8.0     | 0.07                  | 407                  | 645                    | 32.7                 | 19.9                   | 48.3                     | Inv. Steel 10 |
| *In Table 3, Aret(%) represents the area fraction of retained austenite, and Aret[C] represents the amount of dissolved carbon in the retained austenite phase. |          |          |         |                       |                      |                        |                      |                        |                          |               |

**[0084]** As shown in Tables 1-3, the cold-rolled steel sheets, hot-dip galvanized steel sheets, and galvanized steel sheets of Inventive Examples (1-10), in which the steel composition and manufacturing process conditions satisfy the scope of the present invention, were measured to have a high carbon solid solution content in the retained austenite phase and a relatively low sum of the fractions of bainite and martensite, at 9 area% or less. Therefore, based on these results, it can be confirmed that they exhibit a uniform elongation of 18% or more and a hole expansion ratio (HER) of 40% or more.

**[0085]** In contrast, Comparative Examples 1-6, which did not satisfy Relational Expressions 1-3 in terms of steel composition, had a sum of the fractions of bainite and martensite phases that relatively exceeded 9 area%, or had a uniform elongation value of less than 18%, and also had poor hole expansion properties. Furthermore, Comparative Examples 7-8, in which the steel composition was within the scope of the present invention but the manufacturing conditions were outside the scope of the present invention, exhibited poor mechanical properties. Specifically, Comparative Example 7 with a low annealing temperature had poor yield strength, while Comparative Example 8 with an excessively high annealing temperature had poor uniform elongation and hole expansion properties.

**[0086]** Meanwhile, FIG. 1 shows the results of measuring the distribution of MnS inclusions observed across the thickness of the cold-rolled steel sheet of Inventive Example 2 in an embodiment of the present invention. And FIG. 2 shows the results of measuring the distribution of MnS observed across the thickness of the cold-rolled steel sheet of Comparative Example 4. In the case of the inventive example, it can be seen that the sulfur (S) content is relatively low, and the area fraction of MnS inclusions and their distribution are relatively uniform.

**[0087]** Meanwhile, FIG. 3 shows the enrichment amount of (Ni+Cu) measured on the surface layers of the steel sheets of Inventive Example 2 and Comparative Example 4. It can be seen that in the steel with a low (Ni+Cu) content, the surface enrichment amount is relatively small, and depending on the degree of this enrichment, the decrease in surface hardness due to decarburization on the surface of the steel sheet can be compensated.

**[0088]** As described above, although the detailed description of the present invention has described preferred embodiments of the present invention, it is a matter of course that various modifications are possible for those with ordinary skill in the art to which the present invention pertains, without departing from the scope of the present invention. Therefore, the scope of the rights of the present invention should not be limited to the described embodiments, but should be determined by the claims described below as well as their equivalents.

## Claims

1. A cold-rolled steel sheet, comprising: by weight%, C: 0.06 to 0.09%, Mn: 1.2 to 1.6%, Si: 1.3 to 1.7%, P: 0.02% or less, S: 0.007% or less, Al: 0.05% or less, Cr: 0.2% or less (including 0%), Ni: 0.2% or less (including 0%), Cu: 0.3% or less (including 0%), Ti: 0.02% or less (including 0%), Ca: 0.0040% or less (including 0%), N: 0.01% or less, and a sum of Cr+Ni+Cu content of 0.7% or less, with the remainder being Fe and other impurities, wherein the following Relational Expression 1 is satisfied:

[Relational Expression 1]

$$0.08 \leq (\text{Cr} + \text{Ni} + \text{Cu}) / (\text{C} + \text{Mn}) \leq 0.7 \text{ (by weight ratio)}.$$

2. The cold-rolled steel sheet of claim 1, further satisfying the following Relational Expression 2:

[Relational Expression 2]

$$0.06 \leq (\text{Al} + \text{Cu} + \text{Ti} + \text{Ca}) / (\text{Mn} + \text{S}) \leq 0.5 \text{ (by weight ratio)}.$$

3. The cold-rolled steel sheet of claim 1, wherein a difference between a (Ni+Cu) content at a thickness position 0.1  $\mu\text{m}$  directly below a surface layer of the steel sheet and a (Ni+Cu) content at a thickness position 50  $\mu\text{m}$  from the surface layer satisfies the following Relational Expression 3:

[Relational Expression 3]

$$(\text{Ni} + \text{Cu}) \text{ at } 0.1\mu\text{m} - (\text{Ni} + \text{Cu}) \text{ at } 50\mu\text{m} \geq 0.1\% \text{ (by weight ratio)}.$$

4. The cold-rolled steel sheet of claim 1, further comprising one or more selected from the group consisting of Boron (B) in an amount of 0.005% or less and Antimony (Sb) in an amount of 0.03% or less.

5. The cold-rolled steel sheet of claim 1, wherein a hot-dip galvanized layer is formed on one side of the cold-rolled steel sheet.

6. The cold-rolled steel sheet of claim 1, wherein a galvanized layer is formed on one side of the cold-rolled steel sheet.

7. The cold-rolled steel sheet of claim 1, wherein the cold-rolled steel sheet has a microstructure comprising, by area %: bainite + martensite: 9% or less, retained austenite: 5% or less, and a remainder of ferrite.

8. The cold-rolled steel sheet of claim 1, having a tensile strength of 590 MPa or more, a uniform elongation of 18% or more, and a hole expansion ratio (HER) of 40% or more.

9. A method for manufacturing a cold-rolled steel sheet, the method comprising the steps of:

heating a steel slab to a temperature range of 1150 to 1300°C, the steel slab comprising: by weight%, C: 0.06 to 0.09%, Mn: 1.2 to 1.6%, Si: 1.3 to 1.7%, P: 0.02% or less, S: 0.007% or less, Al: 0.05% or less, Cr: 0.2% or less (including 0%), Ni: 0.2% or less (including 0%), Cu: 0.3% or less (including 0%), Ti: 0.02% or less (including 0%), Ca: 0.0040% or less (including 0%), N: 0.01% or less, and a sum of Cr+Ni+Cu content of 0.7% or less, with the remainder being Fe and other impurities, and satisfying the following Relational Expression 1;

obtaining a hot-rolled steel sheet by finish hot-rolling the heated slab in a temperature range of 800 to 1000°C; cooling the hot-rolled steel sheet and coiling it at a temperature of 510 to 620°C;

cold-rolling the coiled steel sheet at a cold reduction ratio of 30 to 70%; and

heating the cold-rolled steel sheet to a temperature of 780 to 820°C, then performing a first slow cooling to 600-700°C, followed by a second rapid cooling to a temperature range of 350 to 450°C at an average cooling rate of 10°C/sec or more, and then holding for 100 to 700 seconds.

[Relational Expression 1]

$$0.08 \leq (\text{Cr} + \text{Ni} + \text{Cu}) / (\text{C} + \text{Mn}) \leq 0.7 \quad (\text{by weight ratio}).$$

10. The method of claim 9, wherein the steel slab further satisfies the following Relational Expression 2:

[Relational Expression 2]

$$0.06 \leq (\text{Al} + \text{Cu} + \text{Ti} + \text{Ca}) / (\text{Mn} + \text{S}) \leq 0.5 \quad (\text{by weight ratio}).$$

11. The method of claim 9, wherein the steel slab further comprises one or more selected from the group consisting of Boron (B) in an amount of 0.005% or less and Antimony (Sb) in an amount of 0.03% or less.

12. The method of claim 9, wherein the manufactured cold-rolled steel sheet has a microstructure comprising, by area %: bainite + martensite: 9% or less, retained austenite: 5% or less, and a remainder of ferrite.

13. The method of claim 9, wherein in the manufactured cold-rolled steel sheet, a difference between a (Ni+Cu) content at a thickness position 0.1  $\mu\text{m}$  directly below a surface layer of the steel sheet and a (Ni+Cu) content at a thickness position 50  $\mu\text{m}$  from the surface satisfies the following Relational Expression 3:

[Relational Expression 3]

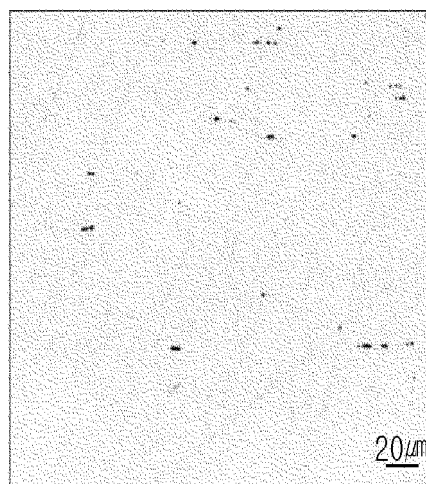
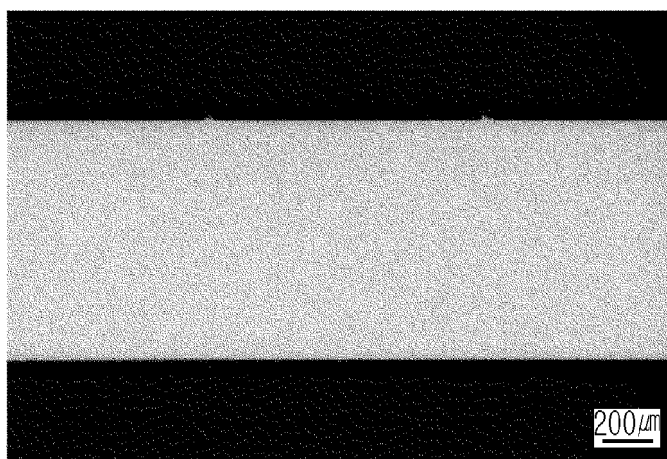
$$(\text{Ni} + \text{Cu}) \text{ at } 0.1\mu\text{m} - (\text{Ni} + \text{Cu}) \text{ at } 50\mu\text{m} \geq 0.1\% \quad (\text{by weight ratio}).$$

14. The method of claim 9, further comprising a step of manufacturing a hot-dip galvanized steel sheet by heating the maintained cold-rolled steel sheet to a temperature range of 400 to 470°C and then performing hot-dip galvanizing.

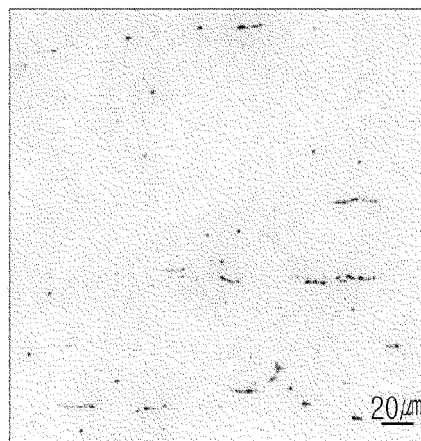
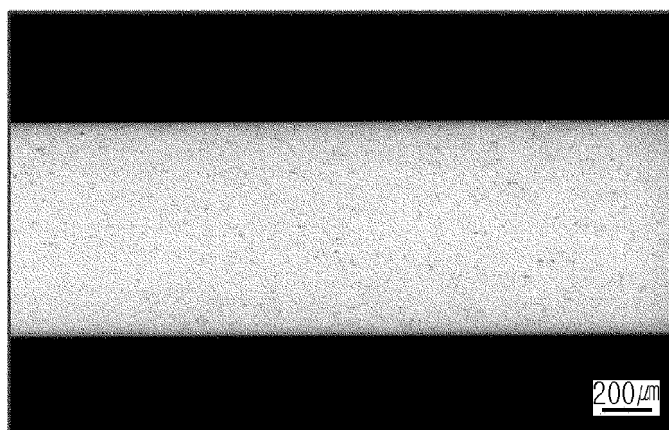
15. The method of claim 14, further comprising a step of manufacturing a galvanized steel sheet by heating the hot-dip galvanized steel sheet to a temperature of 500 to 560°C and then performing an alloying heat treatment.

16. The method of claim 15, further comprising performing skin pass rolling on the galvanized steel sheet with an elongation of 0.1 to 1.5%.

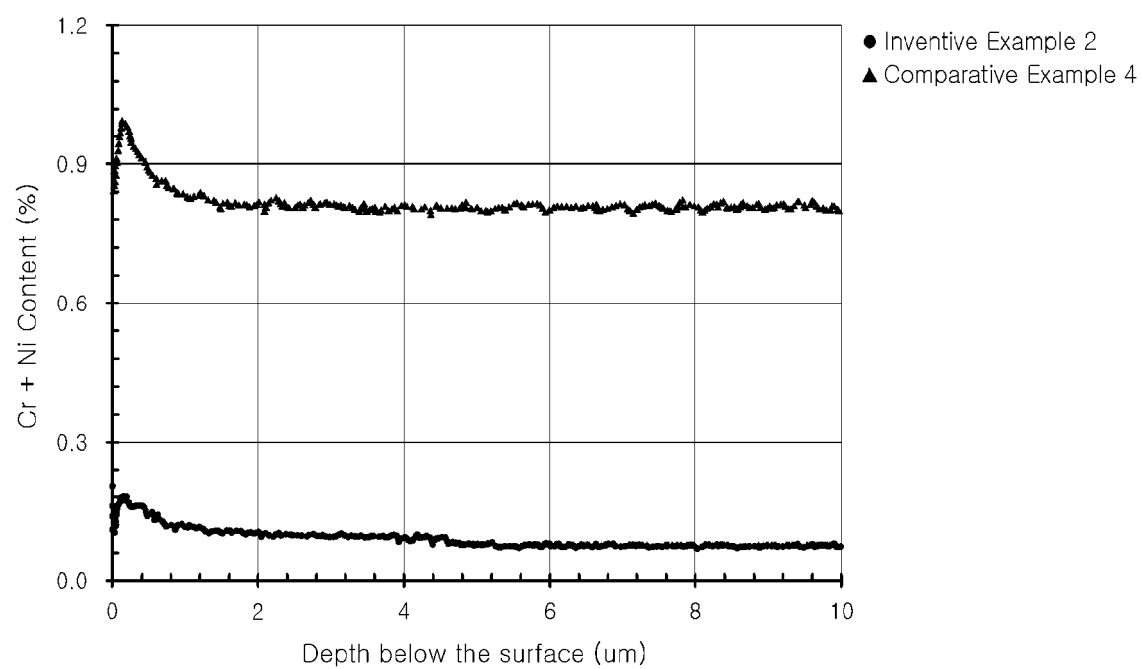
[Fig.1]



[Fig.2]



[Fig.3]



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/020370

## A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/58(2006.01)i; C22C 38/42(2006.01)i; C22C 38/50(2006.01)i; C22C 38/06(2006.01)i; C22C 38/00(2006.01)i;  
C22C 38/54(2006.01)i; C23C 2/06(2006.01)i; C23C 2/28(2006.01)i; C21D 8/02(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 38/58(2006.01); C21D 6/00(2006.01); C21D 8/02(2006.01); C22C 38/00(2006.01); C23C 2/28(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: 냉각(cooling), 페라이트(ferrite), 망간(Mn), 실리콘(Si), 구멍확공성 (HER), 항온변태(isothermal transformation), 서냉(slow cooling)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages             | Relevant to claim No. |
|-----------|------------------------------------------------------------------------------------------------|-----------------------|
| X         | KR 10-2011-0027075 A (POSCO) 16 March 2011 (2011-03-16)<br>See claims 1-7 and tables 1-3.      | 1-2,4-6               |
| Y         |                                                                                                | 3,7-16                |
| Y         | KR 10-2004-0057777 A (POSCO) 02 July 2004 (2004-07-02)<br>See claim 1.                         | 3,7-16                |
| Y         | KR 10-2022-0083906 A (POSCO) 21 June 2022 (2022-06-21)<br>See claims 6 and 9.                  | 14-16                 |
| A         | KR 10-2013-0069699 A (POSCO) 26 June 2013 (2013-06-26)<br>See paragraph [0062] and claims 1-3. | 1-16                  |
| A         | JP 05-070886 A (SUMITOMO METAL IND., LTD.) 23 March 1993 (1993-03-23)<br>See claims 1-4.       | 1-16                  |

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

\* Special categories of cited documents:

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

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“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

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“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

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Date of the actual completion of the international search

14 March 2025

Date of mailing of the international search report

14 March 2025

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT  
Information on patent family members

International application No.  
**PCT/KR2024/020370**

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| Patent document cited in search report |                 |   |  | Publication date (day/month/year) |            | Patent family member(s) |                 | Publication date (day/month/year) |                  |
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| KR                                     | 10-2013-0069699 | A |  | 26                                | June 2013  | KR                      | 10-1299896      | B1                                | 23 August 2013   |
|                                        |                 |   |  |                                   |            | KR                      | 10-2012-0074798 | A                                 | 06 July 2012     |
| JP                                     | 05-070886       | A |  | 23                                | March 1993 | JP                      | 3317303         | B2                                | 26 August 2002   |

**REFERENCES CITED IN THE DESCRIPTION**

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**Patent documents cited in the description**

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- KR 102102005 [0007]