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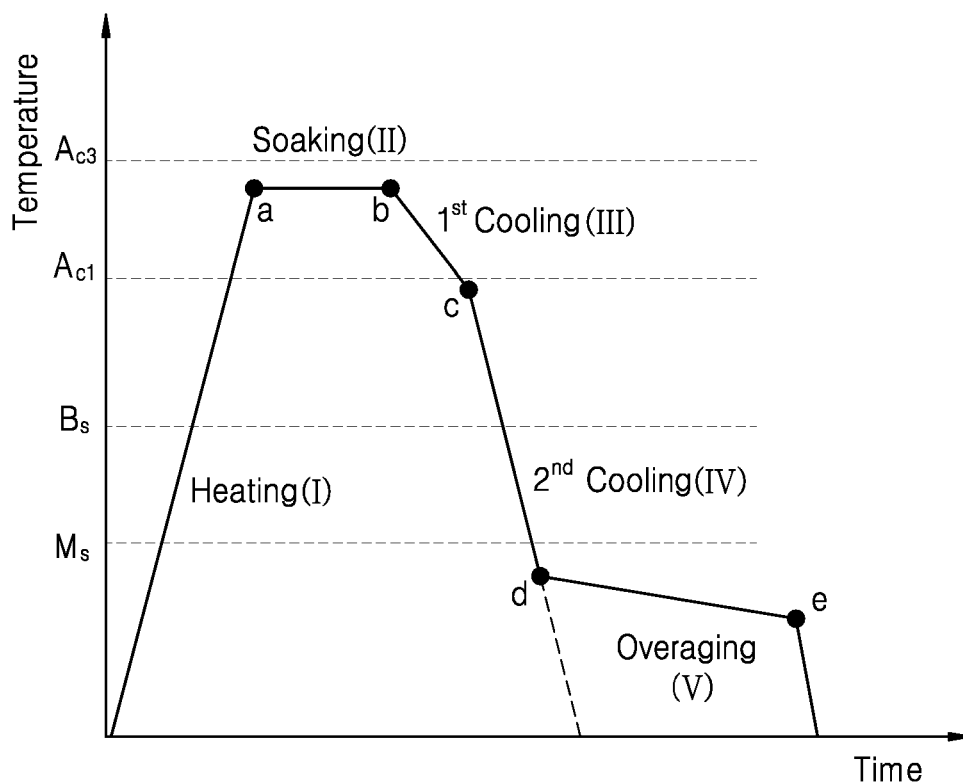
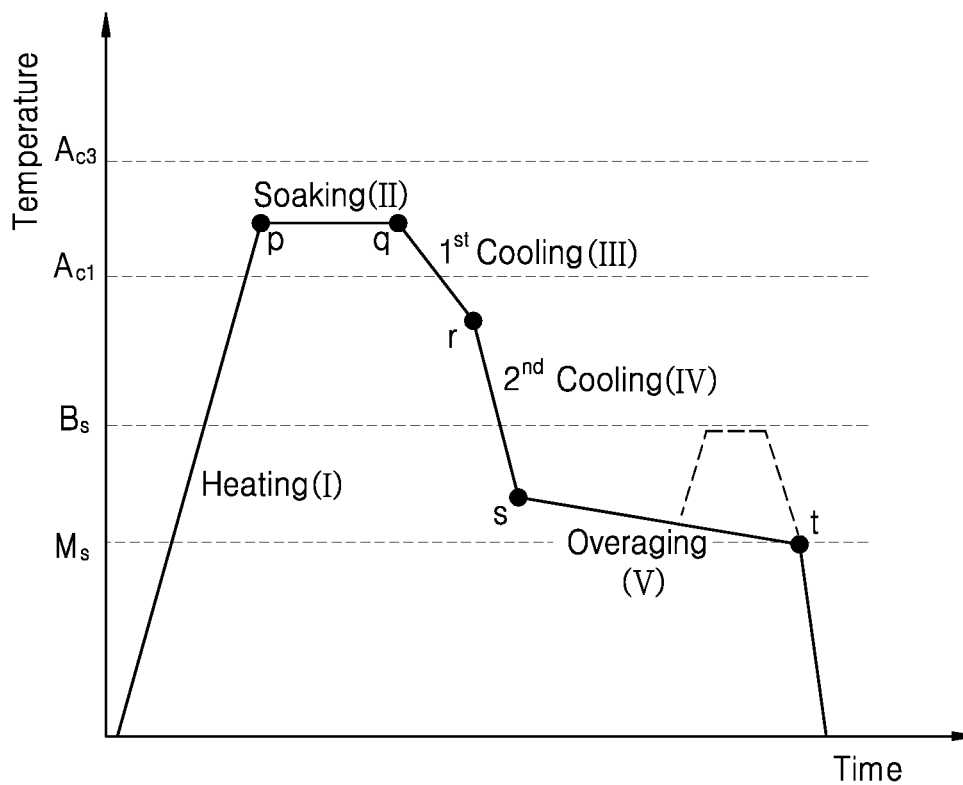
(54) **COLD-ROLLED STEEL SHEET AND METHOD FOR MANUFACTURING SAME**

(57) The present invention provides a cold-rolled steel sheet including 0.15 to 0.20 % by weight of carbon (C), 1.0 to 2.0 % by weight of silicon (Si), 1.5 to 3.0 % by weight of manganese (Mn), greater than 0 % by weight and 0.02 % by weight or less of phosphorus (P), greater than 0 % by weight and 0.003 % by weight or less of sulfur (S), 0.01 to 0.3 % by weight of aluminum (Al), greater than 0 % by weight and 0.01 % by weight or less of nitrogen (N), 48/14·[N] to 0.1 % by weight of titanium (Ti) ([N] is a content (% by weight) of nitrogen), remaining iron (Fe), and other unavoidable impurities, wherein a final micro-

structure of the cold-rolled steel sheet consists of ferrite, needle-shaped residual austenite, a martensite/austenite composite structure, and block-shaped martensite; the area fraction of the ferrite is 30 to 60 %, the area fraction of the needle-shaped residual austenite is 5 to 12 %, the area fraction of the martensite/austenite composite structure is 25 to 50 %, and the area fraction of the block-shaped martensite is 5 to 12 %; and an amount of carbon concentrated in residual austenite is 1.1 % by weight or more.

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FIG. 2

(a) 1<sup>st</sup> Annealing(b) 2<sup>nd</sup> Annealing

**Description**

[Technical Field]

**[0001]** The present invention relates to a cold-rolled steel sheet and a manufacturing method thereof, and more particularly to a cold-rolled ultra-high strength low-carbon steel sheet having excellent formability and a manufacturing method thereof.

[Background Art]

**[0002]** Ultra-high strength steel for automobile steel sheets is being developed to meet the two factors of reducing vehicle weight in response to environmental regulatory issues and strengthening crash safety standards due to strengthening safety regulations. However, since strength and elongation have a trade-off relationship, the problem of decreased formability as strength increases has emerged, and several studies have been conducted to secure the formability of high strength steel.

**[0003]** TRIP (transformation-induced plasticity)-aided steel, which utilizes the TRIP phenomenon that transforms residual austenite into martensite during the transformation of residual austenite within a microstructure, is being developed as a 3rd generation steel sheet that can secure both high strength and high elongation. The physical properties of these TRIP-aided steels are determined by the phase stability and fraction of residual austenite that causes the TRIP phenomenon, so securing stable residual austenite within the microstructure is important in manufacturing the steel.

**[0004]** Related prior art includes Korean Patent Application No. 2018-0033119.

[Disclosure]

[Technical Problem]

**[0005]** Therefore, the present invention has been made in view of the above problems, and it is one object of the present invention to provide a cold-rolled ultra-high strength low-carbon steel sheet having excellent formability and a manufacturing method thereof.

[Technical Solution]

**[0006]** In accordance with one aspect of the present invention, provided is a cold-rolled steel sheet including 0.15 to 0.20 % by weight of carbon (C), 1.0 to 2.0 % by weight of silicon (Si), 1.5 to 3.0 % by weight of manganese (Mn), greater than 0 % by weight and 0.02 % by weight or less of phosphorus (P), greater than 0 % by weight and 0.003 % by weight or less of sulfur (S), 0.01 to 0.3 % by weight of aluminum (Al), greater than 0 % by weight and 0.01 % by weight or less of nitrogen (N), 48/14·[N] to 0.1 % by weight of titanium (Ti) ([N] is a content (% by weight) of nitrogen), remaining iron (Fe), and other unavoidable impurities, wherein a final microstructure of the cold-rolled steel sheet consists of ferrite, needle-shaped residual austenite, a martensite/austenite composite structure, and block-shaped martensite; an area fraction of the ferrite is 30 to 60 %, an area fraction of the needle-shaped residual austenite is 5 to 12 %, an area fraction of the martensite/austenite composite structure is 25 to 50 %, and an area fraction of the block-shaped martensite is 5 to 12 %; and an amount of carbon concentrated in residual austenite is 1.1 % by weight or more.

**[0007]** In the cold-rolled steel sheet, the ferrite may be composed of polygonal ferrite and needle-shaped ferrite, and an area fraction of the needle-shaped ferrite in the ferrite may be 40 % or more.

**[0008]** The cold-rolled steel sheet may have a tensile strength (TS) of 980 to 1180 MPa and an elongation (EI) of 23 to 25 %.

**[0009]** In accordance with another aspect of the present invention, provided is a method of manufacturing a cold-rolled steel sheet, the method including step (a) of reheating steel including 0.15 to 0.20 % by weight of carbon (C), 1.0 to 2.0 % by weight of silicon (Si), 1.5 to 3.0 % by weight of manganese (Mn), greater than 0 % by weight and 0.02 % by weight or less of phosphorus (P), greater than 0 % by weight and 0.003 % by weight or less of sulfur (S), 0.01 to 0.3 % by weight of aluminum (Al), greater than 0 % by weight and 0.01 % by weight or less of nitrogen (N), 48/14·[N] to 0.1 % by weight of titanium (Ti) ([N] is a content (% by weight) of nitrogen), remaining iron (Fe), and other unavoidable impurities; step (b) of hot-rolling the reheated steel; step (c) of cold-rolling the hot-rolled steel; first annealing step (d) of maintaining the cold-rolled steel at a first annealing temperature of (Ac1 + 30 °C) or more and (Ac3 - 30 °C) or less and cooling the cold-rolled steel to a cooling end point temperature of 340 °C or less; and second annealing step (e) of maintaining the steel at a second annealing temperature of Ac1 or more and (Ac3 - 30 °C) or less, cooling the steel to a cooling end point temperature of a martensite transformation onset temperature (Ms) or more and (bainite transformation onset temperature (Bs) - 15 °C) or less, and performing over-aging, wherein the second annealing temperature is lower than the first annealing temperature.

**[0010]** In the method of manufacturing a cold-rolled steel sheet, step (a) may include a step of reheating the steel at 1180 to 1300 °C, step (b) may include a step of performing hot-rolling at a finishing rolling temperature of 850 to 950 °C and a coiling temperature of 450 to 650 °C, and step (c) may include a step of performing cold-rolling at a reduction ratio of 40 to 70 %.

**[0011]** In the method of manufacturing a cold-rolled steel sheet, step (d) may include a process of maintaining the cold-rolled steel at the first annealing temperature for 30 to 120 seconds and cooling the cold-rolled steel to a cooling end point temperature of 340 °C or less at a cooling rate of 15 °C/s or more.

**[0012]** In the method of manufacturing a cold-rolled steel sheet, after performing step (d), an area fraction of ferrite in a microstructure of the steel may be 30 to 50 %.

**[0013]** In the method of manufacturing a cold-rolled steel sheet, step (e) may include a process of maintaining the steel at the second annealing temperature for 30 to 120 seconds, cooling the steel to a cooling end point temperature of a martensite transformation onset temperature ( $M_s$ ) or more and (bainite transformation onset temperature ( $B_s$ ) - 15 °C) or less at a cooling rate of 15 °C/s or more, and performing over-aging for 30 to 300 seconds.

**[0014]** In the method of manufacturing a cold-rolled steel sheet, after performing step (e), a microstructure of the steel may be composed of ferrite, needle-shaped residual austenite, a martensite/austenite composite structure, and block-shaped martensite; and an area fraction of the ferrite may be 30 to 60 %, an area fraction of the needle-shaped residual austenite may be 5 to 12 %, an area fraction of the martensite/austenite composite structure may be 25 to 50 %, and an area fraction of the block-shaped martensite may be 5 to 12 %.

[Advantageous effects]

**[0015]** According to an embodiment of the present invention, a cold-rolled ultra-high strength low-carbon steel sheet having excellent formability and a manufacturing method thereof may be implemented. Specifically, excellent weldability can be secured by designing using low-carbon steel containing a carbon content of 0.2 % by weight or less. During a heat treatment process, a sufficient amount of carbon and manganese can be concentrated in austenite through multiple steps of redistributing alloy elements to achieve an excellent balance of strength and elongation. By securing a tensile strength of 980 MPa or more and an elongation of 23 % or more, cold-rolled ultra-high strength steel with excellent processability can be realized.

**[0016]** Also, the scope of the present invention is not limited to these effects.

[Description of Drawings]

**[0017]**

FIG. 1 is a flowchart schematically showing a method of manufacturing a cold-rolled steel sheet according to an embodiment of the present invention.

FIG. 2 includes diagrams illustrating the outline of (a) the first annealing process and (b) the second annealing process in the method of manufacturing a cold-rolled steel sheet according to an embodiment of the present invention.

FIG. 3 is an image of a microstructure after the first annealing in Example 1 among the experimental examples.

FIG. 4 is an image of a microstructure after the second annealing in Example 1 among the experimental examples.

FIG. 5 is an image of a microstructure after the first annealing in Comparative Example 6 among the experimental examples, FIG. 6 is an image of a final microstructure in Comparative Example 7 among the experimental examples,

FIG. 7 is an image of a final microstructure in Comparative Example 8 among the experimental examples, FIG. 8 is an image of a final microstructure in Comparative Example 9 among the experimental examples, and FIG. 9 includes images of (a) needle-shaped and (b) block-shaped tissues after second annealing and over-aging.

[Best Mode]

**[0018]** A cold-rolled steel sheet according to an embodiment of the present invention and a manufacturing method thereof will be described in detail. The terms described below are terms appropriately selected in consideration of functions thereof in the present invention, and definitions of these terms should be made based on the content throughout this specification. Hereinafter, a cold-rolled ultra-high strength low-carbon steel sheet having excellent formability and a manufacturing method thereof will be described in detail.

**[0019]** Korean Patent Application No. 2018-0033119 proposes a method of manufacturing steel (quenching and partitioning, Q&P) containing tempered martensite and residual austenite through rapid cooling and partitioning heat treatment after annealing steel. Q&P steel has the advantage of being able to obtain physical properties including a tensile strength of 980 MPa or more and an elongation of 21 % or more even with 0.2 % by weight carbon steel. However, Q&P steel has a narrow window for process temperature and has a large ductility deviation, making it difficult to stably secure

high elongation targeted in the present invention.

[0020] Korean Patent Application Publication No. 2017-0113858 proposes a two-time annealing process as a method of securing a microstructure (full structure) before final annealing to increase the ductility of steel by securing lath-shaped ferrite and residual austenite. However, to secure a low-temperature structure with a volume fraction of 90 % or more after first annealing, single-phase annealing is performed, making it impossible to reliably secure a tensile strength of 980 MPa or more in steel with low carbon content. In addition, because high temperature annealing is performed, the lifespan of a furnace may be shortened.

[0021] The present invention discloses a cold rolled ultra-high-strength steel sheet with excellent elongation, applicable to automotive parts, with a tensile strength of 980 MPa or more and an elongation of 23 % or more and a manufacturing method thereof. A microstructure of the cold-rolled steel sheet consists of polygonal ferrite having an area fraction of 20% or more and 50% or less, 40 % or more of needle-shaped ferrite, 5 % or more and 12 % or less of needle-shaped residual austenite, 5% or more of a martensite/austenite composite structure, and a remainder of bainite. In addition, the present invention discloses alloy amount and heat treatment conditions suitable for securing target yield strength, tensile strength, and elongation.

### **Steel sheet**

[0022] A cold-rolled steel sheet according to an embodiment of the present invention consists of 0.15 to 0.20 % by weight of carbon (C), 1.0 to 2.0 % by weight of silicon (Si), 1.5 to 3.0 % by weight of manganese (Mn), greater than 0 % by weight and 0.02 % by weight or less of phosphorus (P), greater than 0 % by weight and 0.003 % by weight or less of sulfur (S), 0.01 to 0.3 % by weight of aluminum (Al), greater than 0 % by weight and 0.01 % by weight or less of nitrogen (N), 48/14·[N] to 0.1 % by weight of titanium (Ti) ([N] is a content (% by weight) of nitrogen), remaining iron (Fe), and other unavoidable impurities.

[0023] Hereinafter, the role and content of each ingredient included in the cold-rolled steel sheet are described.

### **Carbon (C)**

[0024] Carbon (C) is added to secure the strength of steel, and the strength increases as carbon content in a martensite structure increases. In addition, carbon (C) combines with elements such as iron to form carbide, improving strength and hardness. Carbon (C) may be added at a content ratio of 0.15 to 0.20% by weight of the total weight in the cold-rolled steel sheet according to an embodiment of the present invention. When the content of carbon is less than 0.15 % by weight of the total weight, the above-mentioned effect may not be achieved and sufficient strength may not be secured. Conversely, when the content of carbon exceeds 0.20 % by weight of the total weight, weldability and processability may be reduced.

### **Silicon (Si)**

[0025] Silicon (Si) is added to increase strength and suppress carbide formation through the ferrite solid solution-strengthening effect. In addition, silicon is well known as a ferrite stabilizing element, and may increase ductility by increasing ferrite fraction during cooling. In addition, silicon is known as an element that may secure strength by promoting martensite formation by enriching austenite carbon. In addition, silicon is added along with aluminum as a deoxidizer to remove oxygen in steel during a steelmaking process, and may also have a solid solution-strengthening effect. Silicon may be added at a content ratio of 1.0 to 2.0 % by weight of the total weight of the cold-rolled steel sheet according to an embodiment of the present invention. When the silicon content is less than 1.0 % by weight of the total weight, ductility may not be secured and the above-mentioned silicon addition effect may not be properly achieved. Conversely, when the silicon content exceeds 2.0 % by weight of the total weight, oxides such as  $\text{Mn}_2\text{SiO}_4$  may be formed during the manufacturing process, impairing plating properties, and increasing the carbon equivalent, which may reduce weldability. In addition, surface quality may be reduced by generating red scale during reheating and hot rolling, and toughness and plastic processability may be reduced.

### **Manganese (Mn)**

[0026] Manganese (Mn) contributes to improving strength by increasing hardenability, facilitates the formation of a low-temperature transformation phase, and provides the effect of increasing strength through a solid solution-strengthening effect. Manganese may be added at a content ratio of 1.5 to 3.0 % by weight of the total weight of the cold-rolled steel sheet according to an embodiment of the present invention. When the content of manganese is less than 1.5 % by weight, the effect of securing strength described above may not be fully achieved. In addition, when the content of manganese exceeds 3.0 % by weight, processability and delayed fracture resistance may decrease due to the formation or segregation of inclusions such as  $\text{MnS}$ , and the carbon equivalent may be increased, thereby reducing weldability.

**Phosphorus (P)**

[0027] Phosphorus (P) increases strength through a solid solution-strengthening effect and may perform the function of suppressing the formation of carbides. Phosphorus may be added at a content ratio of greater than 0 % by weight and 0.02 % by weight or less of the total weight of the cold-rolled steel sheet according to an embodiment of the present invention. When the content of phosphorus exceeds 0.02 % by weight, a welding area becomes embrittled and low-temperature embrittlement occurs, which reduces press formability and impact resistance.

**Sulfur (S)**

[0028] Sulfur (S) improves the machinability of steel by combining with manganese and titanium and may improve processability by forming a fine MnS precipitate, but generally inhibits ductility and weldability. The sulfur may be added at a content ratio of greater than 0 % by weight and 0.003 % by weight or less of the total weight of the cold-rolled steel sheet according to an embodiment of the present invention. When the content of sulfur exceeds 0.003 % by weight, as the number of FeS inclusions or MnS inclusions increases, toughness and weldability decrease, processability is inferior, and high-temperature cracks may occur due to segregation during continuous casting solidification.

**Aluminum (Al)**

[0029] Aluminum (Al) is an element mainly used as a deoxidizer. Aluminum promotes the formation of ferrite, improves elongation, suppresses the formation of carbides, and stabilizes austenite by increasing carbon concentration in austenite. Aluminum (Al) is preferably added at a content ratio of 0.01 to 0.3 % by weight of the total weight of the cold-rolled steel sheet according to an embodiment of the present invention. When the content of aluminum (Al) is less than 0.01 % by weight, the above-mentioned effects of adding aluminum may not be properly achieved. Conversely, when the content of aluminum (Al) exceeds 0.3 % by weight, aluminum inclusions increase, deteriorating performance, concentrating on the surface of the steel sheet, deteriorating plating properties, and forming AlN in the slab, causing hot-rolled cracks.

**Nitrogen (N)**

[0030] Nitrogen (N) is an element having a solid solution-strengthening effect that may increase the strength of the steel sheet, and is generally an element mixed from the atmosphere. Nitrogen content must be controlled by the degassing process in the steelmaking process. When the nitrogen content exceeds 0.01 % by weight, the welding area becomes embrittled, low-temperature embrittlement occurs, press formability decreases, and impact resistance decreases.

**Titanium (Ti)**

[0031] Titanium (Ti) is a precipitate forming element, which has the effect of precipitating TiN and refining grains. In particular, the nitrogen content inside the steel may be reduced through precipitation of TiN. Titanium is preferably added in an amount of  $48/14 \cdot [N]$  to 0.1 % by weight. When the titanium content is less than  $48/14 \cdot [N]$  % by weight, since the amount of TiC precipitated is small, the effect of adding Ti may be insufficient. When the titanium content exceeds 0.1 % by weight, it is difficult to secure strength by reducing the solid solubility of carbon in the base material.

[0032] As described above, the cold-rolled steel sheet according to an embodiment of the present invention having an alloy element composition may be a cold rolled ultra-high-strength steel sheet having a tensile strength of 980 MPa or more and an elongation of 23 % or more and having excellent elongation. For example, the cold-rolled steel sheet may have a tensile strength (TS) of 980 to 1180 MPa and an elongation (EI) of 23 to 25 %.

[0033] A final microstructure of the cold-rolled steel sheet is composed of ferrite, needle-shaped residual austenite, a martensite/austenite composite structure, and block-shaped martensite. The area fraction of the ferrite is 30 to 60 %, the area fraction of the needle-shaped residual austenite is 5 to 12 %, the area fraction of the martensite/austenite composite structure is 25 to 50 %, and the area fraction of the block-shaped martensite is 25 to 50 %. Carbon content in residual austenite is 1.1 % by weight or more. The ferrite is composed of polygonal ferrite and needle-shaped ferrite, and among the ferrites, the area fraction of the needle-shaped ferrite may be 40 % or more.

[0034] Hereinafter, a method of manufacturing the cold-rolled steel sheet according to an embodiment of the present invention having the above-described composition and the microstructure will be described.

**Method of manufacturing steel sheet**

[0035] FIG. 1 is a flowchart schematically showing a method of manufacturing a cold-rolled steel sheet according to an

embodiment of the present invention.

**[0036]** Referring to FIG. 1, the method of manufacturing a steel sheet according to an embodiment of the present invention sequentially include step (a) (S100) of reheating steel including 0.15 to 0.20 % by weight of carbon (C), 1.0 to 2.0 % by weight of silicon (Si), 1.5 to 3.0 % by weight of manganese (Mn), greater than 0 % by weight and 0.02 % by weight or less of phosphorus (P), greater than 0 % by weight and 0.003 % by weight or less of sulfur (S), 0.01 to 0.3 % by weight of aluminum (Al), greater than 0 % by weight and 0.01 % by weight or less of nitrogen (N),  $48/14 \cdot [N]$  to 0.1 % by weight of titanium (Ti) ([N] is a content (% by weight) of nitrogen), remaining iron (Fe), and other unavoidable impurities; step (b) (S200) of hot-rolling the reheated steel; step (c) (S300) of cold-rolling the hot-rolled steel; first annealing step (d) (S400) of maintaining the cold-rolled steel at a first annealing temperature of  $(Ac1 + 30\text{ }^{\circ}\text{C})$  or more and  $(Ac3 - 30\text{ }^{\circ}\text{C})$  or less and cooling the cold-rolled steel to a cooling end point temperature of  $340\text{ }^{\circ}\text{C}$  or less; and second annealing step (e) (S500) of maintaining the steel at a second annealing temperature of  $Ac1$  or more and  $(Ac3 - 30\text{ }^{\circ}\text{C})$  or less, cooling the steel to a cooling end point temperature of a martensite transformation onset temperature ( $M_s$ ) or more and (bainite transformation onset temperature ( $B_s$ ) -  $15\text{ }^{\circ}\text{C}$ ) or less, and performing over-aging.

**[0037]** Step (a) (S100) may include a step of reheating slab steel having the composition at  $1180$  to  $1300\text{ }^{\circ}\text{C}$ . The slab is manufactured in the form of a semi-finished product by continuously casting molten steel obtained through a steelmaking process. Through a reheating process, ingredient segregation generated during a casting process is homogenized, and the semi-finished product is made ready for hot rolling. When the slab reheating temperature (SRT) is  $1180\text{ }^{\circ}\text{C}$  or less, there is a problem that the segregation of the slab may not be sufficiently reused. When the slab reheating temperature (SRT) exceeds  $1300\text{ }^{\circ}\text{C}$ , the size of austenite grains may increase, and process costs may increase. Reheating of the slab may take 1 to 4 hours. When the reheating time is less than 1 hour, the reduction in segregation is not sufficient. When the reheating time exceeds 4 hours, grain size and process costs may increase.

**[0038]** Step (b) (S200) is a step of hot-rolling the reheated slab. Hot-rolling is performed at a finish delivery temperature (FDT) of  $850$  to  $950\text{ }^{\circ}\text{C}$ . When the finish delivery temperature is less than  $850\text{ }^{\circ}\text{C}$ , rolling load increases rapidly and productivity decreases. When the finish delivery temperature exceeds  $950\text{ }^{\circ}\text{C}$ , strength may decrease as grain size increases. After hot-rolling, cooling is performed at a temperature of  $450$  to  $650\text{ }^{\circ}\text{C}$ , and then winding is performed. When the coiling temperature is less than  $450\text{ }^{\circ}\text{C}$ , the shape of the hot-rolled coil becomes uneven and strength increases, which increases the rolling load during cold-rolling. When the coiling temperature exceeds  $650\text{ }^{\circ}\text{C}$ , surface oxidation may cause defects in post-processing, uneven microstructure may be caused due to differences in cooling rates between the center and edge of the steel sheet, and the inside of the grain may be oxidized.

**[0039]** Step (c) is a step in which the hot-rolled coil is pickled to remove surface scale layers and cold-rolling is performed. The thickness reduction ratio during cold-rolling is approximately 40 to 70 %. As the reduction ratio increases, formability may increase due to the tissue refinement effect. When the reduction is less than 40 % during cold-rolling, it is difficult to obtain a uniform microstructure. When the reduction exceeds 70 %, roll force increases and process load increases.

**[0040]** After cold-rolling, a first annealing process and a second annealing process are performed sequentially. That is, the cold-rolled steel sheet is subjected to the first annealing and second annealing, and is annealed twice in total. The heating rate from room temperature to the first or second annealing temperature section is not limited and may follow the heating rate of normal heating equipment.

**[0041]** Step (d) is a first annealing step including a process of maintaining the cold-rolled steel at a first annealing temperature of  $(Ac1 + 30\text{ }^{\circ}\text{C})$  or more and  $(Ac3 - 30\text{ }^{\circ}\text{C})$  or less and cooling the cold-rolled steel to a cooling end point temperature of  $340\text{ }^{\circ}\text{C}$  or less.

**[0042]** Step (d) is a step of performing annealing at a first annealing temperature of  $(Ac1 + 30\text{ }^{\circ}\text{C})$  or more and  $(Ac3 - 30\text{ }^{\circ}\text{C})$  or less for 30 to 120 seconds to secure ferrite and a dual-phase structure of a low temperature phase. The first annealing process is a process that forms a desirable full structure to secure the lath-shaped needle-shaped ferrite and austenite structure during the second annealing processes. In this specification, 'full structure' refers to the microstructure of steel manufactured by first annealing S400. During the second annealing process, a low-temperature phase tissue undergoes reverse transformation into austenite, and lath-shaped ferrite and austenite microstructure are formed. Here, the low-temperature phase tissue refers to a martensite or bainite phase. This lath-shaped tissue has the characteristic of securing both high strength and high ductility. When annealing in a dual-phase temperature section, primary redistribution of carbon and manganese occurs, enriching carbon and manganese in an austenite region, and increasing the phase stability of austenite.

**[0043]** To satisfy tensile properties including a tensile strength of 980 MPa or more and an elongation of 23 % or more of elongation in the steel of 0.2% by weight or less proposed by the present invention, beyond conventional heat treatment, it is necessary to redistribute carbon and manganese to austenite to increase the strength of martensite to secure sufficient tensile strength and increase the phase stability of residual austenite to secure sufficient ductility. Accordingly, it is desirable to perform the first annealing in a dual-phase temperature section. When the first annealing temperature exceeds  $Ac3$ , austenite crystals become coarse due to high-temperature annealing, and a large amount of austenite with low carbon and manganese content is generated, making it difficult to secure the tensile properties of the final steel. On the other hand, when the first annealing temperature is  $Ac1$  or more and less than  $(Ac1 + 30\text{ }^{\circ}\text{C})$ , after the first annealing

process, the ferrite fraction within the microstructure exceeds 50 %, resulting in an increase in soft and coarse polygonal ferrite within a final microstructure, making it difficult to secure the tensile properties of the steel.

**[0044]** Accordingly, after the first annealing process, the microstructure preferably appears as a dual-phase (DP) tissue composed of ferrite and low-temperature phase. More preferably, to balance strength and ductility, the fraction of ferrite may be limited to 30 to 50 % as an area fraction. When cooling the above-mentioned first annealed steel sheet to room temperature, to suppress the formation of polygonal ferrite, which adversely affects physical properties during cooling, and to secure a low-temperature martensite structure, cooling may be performed at 15 °C/s or more, preferably 25 °C/s or more.

**[0045]** In addition, in a modified embodiment of the present invention, when the microstructure after the first annealing process is a dual-phase (DP) tissue composed of ferrite and low-temperature phase, and the fraction of ferrite is limited to 30 to 50 % as an area fraction, the heat treatment temperature of first annealing may be limited to (Ac1 + 30 °C) or more and (Ac3 - 30 °C) or less.

**[0046]** Step (e) is a second annealing step including a process of maintaining the steel at a second annealing temperature of AAc1 or more and (Ac3 - 30 °C) or less, cooling the steel to a cooling end point temperature of martensite transformation onset temperature (Ms) or more and (bainite transformation onset temperature (Bs) - 15 °C) or less, and then performing over-aging.

**[0047]** Step (e) is a step in which the martensite structure created in the first annealing process undergoes reverse transformation to form lath-shaped ferrite and austenite. During annealing, redistribution of carbon and manganese to austenite occurs along with reverse transformation of the first low-temperature phase. Accordingly, it is desirable to increase the annealing time to ensure sufficient reverse transformation and alloy element redistribution. However, when the annealing time is excessively increased, there is a risk of decreased productivity, so the annealing maintenance time is limited to within 30 to 120 seconds.

**[0048]** The step is a step of cooling the second annealed steel sheet to a temperature between a martensite transformation onset temperature (Ms) and a bainite transformation onset temperature (Bs) and maintaining the temperature for 30 to 300 seconds to induce redistribution of carbon and manganese alloy elements to increase the phase stability of residual austenite. When cooling to the cooling end point temperature of martensite transformation onset temperature (Ms) or more and (bainite transformation onset temperature (Bs) - 15 °C) or less, when the cooling rate is less than 15 °C/s, polygonal ferrite is generated during cooling, resulting in inferior tensile properties of the final steel. Thus, the cooling rate is 15 °C/s or more, preferably 25 °C/s or more. When the cooling end point temperature is higher than (bainite transformation onset temperature (Bs) - 15 °C), during the maintenance step, ferrite or perlite is generated, reducing strength and elongation. When the cooling end point temperature is less than the bainite transformation onset temperature (Bs), in a high-temperature bainite formation section, bainite transformation and carbon redistribution do not occur in a balanced manner. When the cooling end point temperature is lower than the martensite transformation onset temperature (Ms), fresh martensite is created by cooling, greatly increasing the strength of the steel. However, the residual austenite decreases, making it impossible to secure sufficient elongation of 23 % or more targeted in the present invention. Accordingly, the cooling end point temperature is preferably a temperature of martensite transformation onset temperature (Ms) or more and (bainite transformation onset temperature (Bs) - 15 °C) or less. After cooling to the cooling end point temperature, the temperature is maintained for 30 to 300 seconds for additional redistribution of carbon and manganese, and then cooling is performed to room temperature. At this time, the cooling rate up to room temperature is not specifically limited, but is preferably 10 °C/s or more for productivity.

**[0049]** In addition, in the method of manufacturing a cold-rolled steel sheet according to the present invention, the second annealing temperature may be lower than the first annealing temperature. When the second annealing temperature is higher than the first annealing temperature, the austenite fraction generated during second annealing S500 is higher than the low-temperature phase fraction of the tissue after first annealing S400. Austenite, which undergoes reverse transformation in the low-temperature phase, appears as a lamellar structure of needle-shaped ferrite and austenite. However, due to the high annealing temperature, the excessively produced austenite develops into a block-shape, and as a result, a block martensite fraction increases in a final microstructure, greatly increasing the tensile strength of the steel and decreasing the elongation of the steel.

**[0050]** The microstructure of steel finally realized through the above-described heat treatment process is composed of ferrite, needle-shaped residual austenite, a martensite/austenite composite structure, and block-shaped martensite. The area fraction of the ferrite may be 30 to 60 %, the area fraction of the needle-shaped residual austenite may be 5 to 12 %, the area fraction of the martensite/austenite composite structure may be 25 to 50 %, and the area fraction of the block-shaped martensite may be 5 to 12 %.

**[0051]** Within the range of ingredients described in the present invention, the above-described heat treatment process and the steel consisting of the microstructure obtained through the heat treatment process may implement a low carbon cold rolled ultra-high-strength steel sheet having excellent formability by having a tensile strength (TS) of 980 to 1180 MPa and an elongation (El): of 23 to 25 %.

**[0052]** Hereinafter, the annealing process described above is described with reference to the drawings.



**[0053]** FIG. 2 include diagrams showing the outline of (a) first annealing process S400 and (b) second annealing process S500 in the method of manufacturing a cold-rolled steel sheet according to an embodiment of the present invention.

### **First annealing S400**

**[0054]** Referring to FIG. 2A, the section a-b corresponds to a step of maintaining at a first annealing temperature of ( $Ac1 + 30\text{ }^{\circ}\text{C}$ ) or more and ( $Ac3 - 30\text{ }^{\circ}\text{C}$ ) or less, the section b-c is the first half of the cooling section and corresponds to a slow cooling process, the sections c-d is the latter half of the cooling section and corresponds to a rapid cooling process, and the section d-e corresponds to an over-aging process. In a modified embodiment of the present invention, the slow cooling process of the section b-c and the over-aging process of the section d-e may be omitted.

**[0055]** The first annealing process may be maintained at a first annealing temperature of ( $Ac1 + 30\text{ }^{\circ}\text{C}$ ) or more and ( $Ac3 - 30\text{ }^{\circ}\text{C}$ ) or less for 30 to 120 seconds. When the carbon content proposed in this embodiment is 0.2% by weight or less, the redistribution of alloy elements must be increased compared to existing steel types to secure the tensile strength of the steel. Accordingly, the first annealing process is performed at a dual-phase temperature range to induce primary redistribution of alloy elements. At this time, when the annealing temperature is too low, a large amount of polygonal ferrite is formed within the microstructure after the first annealing process, making it difficult to secure sufficient tensile strength. When the annealing temperature exceeds ( $Ac3 - 30\text{ }^{\circ}\text{C}$ ), high-temperature annealing causes grain coarsening and an increase in lean austenite fraction with low alloy elements, making it difficult to achieve the target tensile properties. When the holding time exceeds 120 seconds, the grain size may become coarse and productivity may decrease. The annealed cold rolling steel is cooled to a temperature of  $340\text{ }^{\circ}\text{C}$  or less at a cooling rate of  $15\text{ }^{\circ}\text{C/s}$  or more. At this time, when the cooling end point temperature exceeds  $340\text{ }^{\circ}\text{C}$ , it is difficult to obtain a lath-shaped tissue in the second annealing process due to carbide precipitation. When the cooling rate is less than  $15\text{ }^{\circ}\text{C/s}$ , a large amount of polygonal ferrite is generated during cooling, which is disadvantageous in securing tensile strength.

**[0056]** The sections b-c is a step of slowly cooling the annealed steel sheet. When cooling the annealed steel sheet, a slow cooling section may be included depending on heat treatment equipment. When the slow cooling section is included, the slow cooling end point temperature or cooling speed is not specifically limited, but to prevent a large amount of polygonal ferrite from being generated during cooling, preferably, the slow cooling end point temperature may be  $740\text{ }^{\circ}\text{C}$  or more, and the cooling speed may be  $-5\text{ }^{\circ}\text{C/s}$  or more.

**[0057]** The section c-d is the latter part of the cooling section and corresponds to the rapid cooling process, and is a step of cooling the steel sheet cooled through the slow cooling process to a temperature of  $340\text{ }^{\circ}\text{C}$  or less. When cooling the first annealed steel sheet or first cooled steel sheet, to suppress the formation of polygonal ferrite, which has a negative effect on physical properties, and to form bainite or martensite, which is a low-temperature phase, cooling is performed at  $-15\text{ }^{\circ}\text{C/s}$  or more, preferably  $25\text{ }^{\circ}\text{C/s}$  or more. The cooling rate is maintained up to a temperature of martensite transformation onset temperature ( $M_s$ ) or less, expressed in Equation (1) below. Then, cooling is performed up to room temperature through the over-aging section of equipment. Alternatively, cooling may be performed directly up to room temperature by omitting the over-aging section.

$$M_s\text{ (}^{\circ}\text{C)} = 491.1 - 302.6[C] - 14.5[Si] - 30.6[Mn] - 16.6[Ni] - 8.9[Cr] + 2.4[Mo] - 11.3[Cu] + 8.58[Co] + 7.4[W] \quad \text{Equation (1)}$$

**[0058]** Here, [C], [Si], [Mn], [Ni], [Cr], [Mo], [Cu], [Co], and [W] represent mass% of carbon, silicon, manganese, nickel, chromium, molybdenum, copper, cobalt, and tungsten in the steel.

### **Second annealing S500**

**[0059]** Referring to FIG. 2B, the section p-q corresponds to a step of maintaining at a second annealing temperature of  $Ac1$  or more and ( $Ac3 - 30\text{ }^{\circ}\text{C}$ ) or less. The section q-r is the first half of the cooling section and corresponds to a slow cooling section. The section r-s is the second half of the cooling section and corresponds to a rapid cooling section. The section s-t corresponds to an over-aging section. In addition, in the second annealing process shown in FIG. 2B, the dotted line profile between bainite transformation onset temperature ( $B_s$ ) and martensite transformation onset temperature ( $M_s$ ) corresponds to the case where a plating process is performed in a plating bath.

**[0060]** The second annealing process may be maintained at a second annealing temperature of  $Ac1$  or more and ( $Ac3 - 30\text{ }^{\circ}\text{C}$ ) or less for 30 to 120 seconds. In addition, the second annealing temperature may be lower than the first annealing temperature. A step of performing dual-phase annealing at a temperature of  $Ac1$  or more and less than first annealing temperature for 30 to 120 seconds is performed. This step is a step in which the low-temperature phase tissue generated in first annealing S400 is reverse transformed to form lath-shaped ferrite and austenite. During annealing, reverse transformation of the first low-temperature phase and redistribution of carbon (C) and manganese (Mn) to austenite

occur. Accordingly, a longer annealing time is desirable for sufficient reverse transformation and alloy element redistribution. However, when the annealing time increases excessively, there is a risk of decreased productivity, so the annealing maintenance time is limited to within 30 seconds to 120 seconds. When the annealing temperature of second annealing S500 is higher than the annealing temperature of first annealing S400, the austenite fraction generated in second annealing is larger than the low-temperature phase fraction in the full structure. As a result, the development of lath-shaped austenite, which undergoes reverse transformation in the low-temperature phase, is inhibited, and block-shaped austenite is generated in an excess fraction. This block-shaped austenite reduces the phase stability of austenite by reducing carbon (C) and manganese (Mn) that are redistributed to lath-shaped austenite. This impedes the effectiveness of first annealing S400 in creating the lath-shaped tissue required to secure the elongation sought to be achieved in the present invention. Accordingly, second annealing S500 is preferably performed at a lower temperature than first annealing S400.

**[0061]** Then, at a cooling rate of 15 °C/s or more, cooling is performed to a cooling end point temperature of martensite transformation onset temperature (Ms) or more and (bainite transformation onset temperature (Bs) - 15 °C) or less, and over-aging is performed for 30 to 300 seconds to induce redistribution of carbon (C) and manganese (Mn) alloy elements to increase the phase stability of residual austenite.

**[0062]** Bainite transformation onset temperature (Bs) may be expressed by Equation (2) below.

### Equation (2)

$$Bs\ (^{\circ}C) = 656 - 57.7[C] - 75[Si] - 35[Mn] - 15.3[Ni] - 34[Cr] - 41.2[Mo]$$

**[0063]** Here, [C], [Si], [Mn], [Ni], [Cr], and [Mo] represent mass% of carbon, silicon, manganese, nickel, chromium, and molybdenum in the steel.

**[0064]** When cooling to a temperature of martensite transformation onset temperature (Ms) or more and (bainite transformation onset temperature (Bs) - 15 °C) or less, when the cooling rate is less than 15 °C/s, polygonal ferrite is generated during cooling, resulting in inferior tensile properties of the final steel. Accordingly, the cooling rate should be 15 °C/s or more, preferably 25 °C/s or more.

**[0065]** When the cooling end point temperature is bainite transformation onset temperature (Bs) or less and greater than (bainite transformation onset temperature (Bs) - 15 °C), during the maintenance step, austenite transforms into ferrite or perlite, causing a decrease in strength and elongation. When the cooling end point temperature is less than the bainite transformation onset temperature (Bs), due to lack of carbon redistribution, it is difficult to ensure phase stability of residual austenite. Conversely, when the cooling end point temperature is less than the martensite transformation onset temperature (Ms), rash martensite is created, greatly increasing the strength of the steel, but on the other hand, residual austenite is reduced, making it impossible to secure sufficient elongation of more than 23 %, which is the goal in the present invention. In addition, when the retention time is less than 30 seconds, the redistribution effect may decrease due to insufficient redistribution time, and when the retention time exceeds 300 seconds, productivity may decrease.

**[0066]** After cooling to the cooling end point temperature, over-aging is performed for 30 to 300 seconds for redistribution of carbon (C) and manganese (Mn), and then cooling is performed to room temperature. During over-aging, the temperature does not need to be maintained isothermally at the cooling end point temperature. Cooling may be done as needed, but the temperature must be Ms or more to prevent the formation of fresh martensite. In addition, the cooling rate up to room temperature is not specifically limited, but is preferably 10 °C/s or more for productivity. The redistribution effect of carbon (C) and manganese (Mn) during over-aging varies depending on the austenite shape, and is greater in a needle shape than in a block shape. In the needle shape, the diffusion distance of carbon (C) and manganese (Mn) is shorter, so diffusion occurs more easily during the same time. As shown in FIG. 9 and Table 1, as a result of analyzing the content of carbon (C) and manganese (Mn) in needle-shaped and block-shaped tissues after over-aging, it was confirmed that more carbon (C) and manganese (Mn) thickening occurred in the needle-shaped tissue. As a result, in the microstructure after final cooling, needle-shaped austenite remains as a martensite/austenite composite structure, and block-shaped austenite remains as block-shaped martensite.

[Table 1]

% by weight	Needle-shaped	Block-shaped
Carbon (C)	0.6±0.05	0.3±0.05
Manganese (Mn)	3.5±0.5	2.25±0.25

**[0067]** According to the cold-rolled steel sheet and the manufacturing method thereof according to the technical idea of

the present invention, excellent weldability may be secured by designing using low-carbon steel containing a carbon content of 0.2 % by weight or less. During a heat treatment process, a sufficient amount of carbon (C) and manganese (Mn) may be concentrated in austenite through multiple steps of redistributing alloy elements to achieve an excellent balance of strength and elongation. By securing a tensile strength of 980 MPa or more and an elongation of 23 % or more, cold-rolled ultra-high strength steel with excellent processability may be provided.

## Experimental examples

**[0068]** Hereinafter, to help understand the present invention, preferred experimental examples are presented. However, the following experimental examples are only intended to help understand the present invention, and the present invention is not limited to the following experimental examples.

### 1. Manufacture of specimens

**[0069]** In this experimental example, specimens with the alloy element composition (unit: % by weight) shown in Table 2 are provided.

[Table 2]

C	Si	Mn	P	S	Al	Ti	N	Fe
0.18	1.70	2.30	0.01	0.001	0.03	0.015	0.003	Bal.

**[0070]** The composition of Table 2, which is the composition of the cold-rolled steel sheet according to an embodiment of the present invention, includes 0.15 to 0.20 % by weight of carbon (C), 1.0 to 2.0 % by weight of silicon (Si), 1.5 to 3.0 % by weight of manganese (Mn), greater than 0 % by weight and 0.02 % by weight or less of phosphorus (P), greater than 0 % by weight and 0.003 % by weight or less of sulfur (S), 0.01 to 0.3 % by weight of aluminum (Al), greater than 0 % by weight and 0.01 % by weight or less of nitrogen (N), 48/14·[N] to 0.1 % by weight of titanium (Ti) ([N] is a content (% by weight) of nitrogen), and the remaining iron (Fe). According to the ingredients in Table 2, the bainite transformation onset temperature (Bs) is 437.6 °C, and the martensite transformation onset temperature (Ms) is 341.6 °C. The temperature is calculated by the relationship below.

$$Bs (^{\circ}C) = 656 - 57.7[C] - 75[Si] - 35[Mn] - 15.3[Ni] - 34[Cr] - 41.2[Mo]$$

$$Ms (^{\circ}C) = 491.1 - 302.6[C] - 14.5[Si] - 30.6[Mn] - 16.6[Ni] - 8.9[Cr] + 2.4[Mo] - 11.3[Cu] + 8.58[Co] + 7.4[W]$$

**[0071]** In addition, according to the ingredients in Table 2, the Ac1 temperature is 754 °C, and the Ac3 temperature is 900 °C.

**[0072]** In an experimental example of the present invention, steel having the composition was reheated at 1250 °C for 4 hours, hot-rolled to a thickness of 3.5 mm at a finish delivery temperature (FDT) of 850 °C, and then wound at a coiling temperature of 600 °C. Afterwards, surface layer oxidized scales was removed through pickling and cold-rolling was performed to a thickness of 1.2 mm. Afterwards, the cold-rolled steel sheet was heat-treated twice in succession according to the configuration disclosed in FIG. 2.

### 2. Process conditions and physical property evaluation

**[0073]** Table 3 shows the process conditions for first annealing and second annealing applied in the experimental example of the present invention.

[Table 3]

5		A. First annealing temperature	B. First annealing time	C. Slow cooling end temperature	D. Rapid cooling end temperature	E. Over-aging time	F. Second annealing temperature	G. Second annealing time	H. Rapid cooling end temperature	I. Over-aging end temperature	J. Over-aging time
	Example 1	850	60	800	340	180	830	60	400	360	180
10	Example 2	850	60	800	340	180	840	120	400	360	300
	Example 3	860	60	800	340	180	830	60	400	360	180
	Example 4	850	60	-	25	-	830	60	400	360	180
15	Comparative Example 1	850	60	800	340	180	830	60	440	400	180
	Comparative Example 2	850	60	800	340	180	850	60	440	400	180
20	Comparative Example 3	850	60	800	340	180	850	60	400	360	25
	Comparative Example 4	850	60	800	340	180	850	60	320	280	180
25	Comparative Example 5	890	60	800	340	180	830	60	400	360	180
	Comparative Example 6	910	60	800	340	180	830	60	440	400	180
30	Comparative Example 7	910	60	800	340	180	830	60	400	360	180
	Comparative Example 8	850	60	800	340	180	870	60	400	360	180
35	Comparative Example 9	-	-	-	-	-	850	60	400	360	180

**[0074]** In Table 3, item A is the annealing temperature of the first annealing process S400 and corresponds to the annealing temperature of section a-b in FIG. 2A. Item B is the annealing time of the first annealing process S400 and corresponds to the process time of section a-b in FIG. 2A. Item C is the slow cooling end temperature of the first annealing process S400 and corresponds to the temperature at point c, which is the end temperature of the slow cooling process in section b-c in FIG. 2A. Item D is the rapid cooling end temperature of the first annealing process S400 and corresponds to the temperature at point d, which is the end temperature of the rapid cooling process in section c-d in FIG. 2A. Item E is the over-aging time of the first annealing process S400 and corresponds to the process time of the over-aging process in section d-e in FIG. 2A. In addition, item F in Table 3 is the annealing temperature of the second annealing process S500 and corresponds to the annealing temperature of section p-q in FIG. 2B. Item G is the annealing time of the second annealing process S500 and corresponds to the process time of section p-q in FIG. 2B. Item H is the rapid cooling end temperature of the second annealing process S500 and corresponds to the temperature at point s, which is the end temperature of the rapid cooling process in section r-s in FIG. 2B. Item I is the over-aging end temperature of the second annealing process S500 and corresponds to the temperature at point t, which is the end temperature of the over-aging process in section s-t in FIG. 2B. Item J is the over-aging time of the second annealing process S500 and corresponds to the process time of the over-aging process in section s-t in FIG. 2B.

[Table 4]

55		A. Ferrite	B. Low-temperature phase	C. Ferrite	D. PF	E. Lath F	F. RA	G. M/A	H. Block M	I. C in RA
	Example 1	43	57	53	18	35	8.9	33	5.1	1.12

(continued)

	A. Ferrite	B. Low- temperature phase	C. Ferrite	D. PF	E. Lath F	F. RA	G. M/A	H. Block M	I. C in RA
Example 2	45	55	43	13	30	9.0	38	10.0	1.15
Example 3	30	70	55	17	38	9.4	30	5.6	1.21
Example 4	37	63	56	19	37	8.3	26	9.7	1.18
Comparative Example 1	45	55	55	18	37	4.0	29	12.0	1.03
Comparative Example 2	45	55	41	10	31	4.3	41	13.7	1.07
Comparative Example 3	45	55	44	11	33	4.0	39	13.0	0.94
Comparative Example 4	45	55	45	11	34	3.1	35	16.9	1.15
Comparative Example 5	6	94	44	7	37	12.5	42	1.5	1.00
Comparative Example 6	0	100	42	4	38	13.7	35	9.3	1.00
Comparative Example 7	0	100	42	4	38	15.6	40	2.4	1.07
Comparative Example 8	45	55	40	5	35	4.0	36	20.0	1.02
Comparative Example 9	-	-	55	39	16	3.0	24	18.0	1.17

**[0075]** Table 4 shows the area fraction (unit: %) of the microstructure and an amount (unit: % by weight) of carbon concentrated in the residual austenite in an experimental example of the present invention. The microstructure was analyzed using a scanning electron microscope (SEM), and XRD analysis was used to analyze the residual austenite fraction and carbon content in residual austenite. In Table 4, item A is the area fraction of the ferrite phase implemented after first annealing, item B is the area fraction of the low-temperature phase implemented after first annealing, item C is the area fraction of the ferrite phase implemented after second annealing, item D is the area fraction of polygonal ferrite among ferrites implemented after second annealing, item E is the area fraction of needle-shaped ferrite among ferrites implemented after second annealing, item F is the area fraction of needle-shaped residual austenite implemented after second annealing, item G is the area fraction of the martensite/austenite composite structure implemented after second annealing, item H is the area fraction of the block-shaped martensite implemented after second annealing, and item I is an amount of carbon concentrated in the residual austenite implemented after second annealing.

**[0076]** Table 5 shows tensile properties in an experimental example of the present invention. Tensile properties were evaluated by performing a tensile test according to KS No. 5 standard using Zwick/Roell Corp Z100.

**[0077]** In Table 5, item TS represents tensile strength (unit: MPa), item T.E1 represents elongation (unit: %), and item TS  $\times$  T.E1 represents the product (unit: MPa %) of tensile strength and elongation.

[Table 5]

	TS	T.E1	TS $\times$ T.E1
Example 1	985	24.3	23,936
Example 2	1011	23.4	23,657
Example 3	990	23.7	23,463
Example 4	1029	23.8	24,490
Comparative Example 1	1053	18.6	19,586
Comparative Example 2	1090	18.1	19,729
Comparative Example 3	1106	17.7	19,576
Comparative Example 4	1158	14.6	16,907
Comparative Example 5	968	23.8	23,038
Comparative Example 6	1022	20.8	21,258
Comparative Example 7	946	25.1	23,745
Comparative Example 8	1142	16.7	19,071

(continued)

	TS	T.EI	TS × T.EI
Comparative Example 9	1164	15.8	18,391

**[0078]** Referring to Tables 2 to 5, in the case of Examples 1 to 4, by properly performing first annealing S400 and second annealing S500 suggested by the present invention, a tensile strength of 980 MPa or more (e.g., 980 to 1180 MPa), an elongation of 23 % or more (e.g., 23 to 25 %), and tensile properties of TS x EI 22,000 MPa % or more to be achieved in the present invention are satisfied. Referring to FIG. 3, the tissue after first annealing S400 in Example 1, that is, the full structure, consists of 43 % ferrite and 57 % low-temperature phase, satisfying the conditions of the present invention (area fraction of ferrite: 30 to 50%). The microstructure after second annealing S500 in Example 1 is the same as FIG. 4. It can be confirmed that ferrite, needle-shaped residual austenite, martensite/austenite composite structure, and block-shaped martensite are composed of the target fractions of the present invention.

**[0079]** In Comparative Examples 1 to 4, first annealing S400 was performed at a dual-phase temperature of 850°C, and a sufficient amount of ferrite (45%) was secured within the microstructure after first annealing. However, in second annealing S500, the redistribution of the alloy elements was not performed smoothly, and the residual austenite fraction and phase stability were not sufficiently secured. Accordingly, the tensile strength was sufficiently high at over 1000 MPa, but elongation was significantly less than the 23 % desired to be achieved in the present invention.

**[0080]** Specifically, in the case of Comparative Examples 1 and 2, in second annealing S500, the cooling end point temperature was above the bainite transformation onset temperature (Bs), so redistribution of carbon (C) and manganese (Mn) was not effective during the holding time after the cooling end point. Elongation did not reach the target (23 % or more).

**[0081]** In Comparative Example 3, like Examples 1 and 2, cooling was completed at a proper temperature of martensite transformation onset temperature (Ms) or more and (bainite transformation onset temperature (Bs) - 15 °C) or less. However, the over-aging time was short, less than 30 seconds, so sufficient redistribution was not achieved, and the elongation was below the target (more than 23 %). In Example 2, the holding time is increased in second annealing S500 compared to Comparative Example 3. It can be seen that redistribution of carbon (C) and manganese (Mn) is sufficiently achieved and elongation is greatly increased, and sufficient holding time is required to increase elongation.

**[0082]** In Comparative Example 4, the cooling end temperature in second annealing S500 is less than the martensite transformation onset temperature (Ms). At the end of cooling, martensite was formed and the austenite fraction was reduced, and redistribution of carbon (C) and manganese (Mn) was not effective due to low temperature, so elongation was below the target value (23 % or more).

**[0083]** In Comparative Examples 5, 6, and 7, in first annealing S400, the annealing temperature is high, so the ferrite fraction within the microstructure after first annealing is 6 % and 0 %, respectively, which are outside the range (30 to 50%) suggested in the present invention.

**[0084]** Referring to FIG. 5 showing the full structure after first annealing S400 in Comparative Example 6, by performing single-phase annealing, it can be confirmed that the full structure is composed of a low-temperature phase after first annealing S400. In this way, as the annealing temperature of first annealing S400 increases, the ferrite fraction in the full structure decreases. As the low-temperature phase fraction increases, the polygonal ferrite decreases in the final microstructure after second annealing S500, the fraction of needle-shaped ferrite and residual austenite increases, and the fraction of block-shaped martensite decreases.

**[0085]** Referring to FIG. 6 showing the final microstructure of Comparative Example 7, the overall microstructure is composed of needle-shaped ferrite, a martensite/austenite composite structure, and residual austenite. Because there is very little block-shaped martensite that contributes to an increase in strength, in Comparative Examples 5 and 7, elongation satisfies the target value (23 % or more) of the present invention, but tensile strength does not.

**[0086]** In Comparative Example 6, in second annealing S500, the cooling end temperature was set to 440 °C, which exceeds the bainite transformation onset temperature (Bs), and the redistribution of carbon (C) and manganese (Mn) was reduced after the end of cooling to secure the tensile strength above 1022 MPa. However, due to lack of redistribution, elongation was below the target value (23 % or more).

**[0087]** In Comparative Example 8, the annealing temperature (second annealing temperature) of second annealing S500 is higher than the annealing temperature (first annealing temperature) of first annealing S400, which is against the heat treatment method proposed in the present invention. When the second annealing temperature is higher than the first annealing temperature, the austenite fraction produced in second annealing S500 is higher than the low-temperature phase fraction of the tissue after first annealing S400. Austenite that undergoes reverse transformation in the low-temperature phase appears in a lamellar structure of needle-shaped ferrite and austenite, but austenite that is excessively produced due to high annealing temperature develops into a block shape. As a result, block martensite fraction increases in the final microstructure, significantly increasing the tensile strength of the steel but reducing elongation (see FIG. 7).

**[0088]** Comparative Example 9 is a case in which only conventional one-time annealing was performed, and a microstructure consisting of block-shaped bainite, martensite, and ferrite appears, as shown in FIG. 8. High tensile strength and low elongation are observed due to high block-shaped martensite fraction, a low martensite/austenite composite structure, and residual austenite fraction.

**[0089]** According to the experimental examples described so far, when two-phase tissue consisting of ferrite and low-temperature phase is not secured in first annealing S400, or when needle-shaped ferrite and austenite are not properly secured in second annealing S500, it is difficult to secure the physical balance between tensile strength and elongation targeted in the present invention.

**[0090]** The present invention has been described with reference to the embodiments thereof, but various changes or modifications can be made by those skilled in the art. As long as these changes and modifications do not depart from the scope of the present invention, they can be said to belong to the present invention. Therefore, the scope of the rights of the present invention should be determined by the claims described below.

## Claims

1. A cold-rolled steel sheet, comprising 0.15 to 0.20 % by weight of carbon (C), 1.0 to 2.0 % by weight of silicon (Si), 1.5 to 3.0 % by weight of manganese (Mn), greater than 0 % by weight and 0.02 % by weight or less of phosphorus (P), greater than 0 % by weight and 0.003 % by weight or less of sulfur (S), 0.01 to 0.3 % by weight of aluminum (Al), greater than 0 % by weight and 0.01 % by weight or less of nitrogen (N), 48/14·[N] to 0.1 % by weight of titanium (Ti) ([N] is a content (% by weight) of nitrogen), remaining iron (Fe), and other unavoidable impurities,

wherein a final microstructure of the cold-rolled steel sheet consists of ferrite, needle-shaped residual austenite, a martensite/austenite composite structure, and block-shaped martensite;

an area fraction of the ferrite is 30 to 60 %, an area fraction of the needle-shaped residual austenite is 5 to 12 %, an area fraction of the martensite/austenite composite structure is 25 to 50 %, and an area fraction of the block-shaped martensite is 5 to 12 %; and

an amount of carbon concentrated in residual austenite is 1.1 % by weight or more.

2. The cold-rolled steel sheet according to claim 1, wherein the ferrite is composed of polygonal ferrite and needle-shaped ferrite, and an area fraction of the needle-shaped ferrite in the ferrite is 40 % or more.

3. The cold-rolled steel sheet according to claim 1, wherein the cold-rolled steel sheet has a tensile strength (TS) of 980 to 1180 MPa and an elongation (El) of 23 to 25 %.

4. A method of manufacturing a cold-rolled steel sheet, comprising:

step (a) of reheating steel comprising 0.15 to 0.20 % by weight of carbon (C), 1.0 to 2.0 % by weight of silicon (Si), 1.5 to 3.0 % by weight of manganese (Mn), greater than 0 % by weight and 0.02 % by weight or less of phosphorus (P), greater than 0 % by weight and 0.003 % by weight or less of sulfur (S), 0.01 to 0.3 % by weight of aluminum (Al), greater than 0 % by weight and 0.01 % by weight or less of nitrogen (N), 48/14·[N] to 0.1 % by weight of titanium (Ti) ([N] is a content (% by weight) of nitrogen), remaining iron (Fe), and other unavoidable impurities; step (b) of hot-rolling the reheated steel;

step (c) of cold-rolling the hot-rolled steel;

first annealing step (d) of maintaining the cold-rolled steel at a first annealing temperature of (Ac1 + 30 °C) or more and (Ac3 - 30 °C) or less and cooling the cold-rolled steel to a cooling end point temperature of 340 °C or less; and second annealing step (e) of maintaining the steel at a second annealing temperature of Ac1 or more and (Ac3 - 30 °C) or less, cooling the steel to a cooling end point temperature of a martensite transformation onset temperature (Ms) or more and (bainite transformation onset temperature (Bs) - 15 °C) or less, and performing over-aging, wherein the second annealing temperature is lower than the first annealing temperature.

5. The method according to claim 4, wherein step (a) comprises a step of reheating the steel at 1180 to 1300 °C,

step (b) comprises a step of performing hot-rolling at a finishing rolling temperature of 850 to 950 °C and a coiling temperature of 450 to 650 °C, and

step (c) comprises a step of performing cold-rolling at a reduction ratio of 40 to 70 %.

6. The method according to claim 4, wherein step (d) comprises a process of maintaining the cold-rolled steel at the first

annealing temperature for 30 to 120 seconds and cooling the cold-rolled steel to a cooling end point temperature of 340 °C or less at a cooling rate of 15 °C/s or more.

- 5        7. The method according to claim 6, wherein, after performing step (d), an area fraction of ferrite in a microstructure of the steel is 30 to 50%.
- 10       8. The method according to claim 4, wherein step (e) comprises a process of maintaining the steel at the second annealing temperature for 30 to 120 seconds, cooling the steel to a cooling end point temperature of a martensite transformation onset temperature ( $M_s$ ) or more and (bainite transformation onset temperature ( $B_s$ ) - 15 °C) or less at a cooling rate of 15 °C/s or more, and performing over-aging for 30 to 300 seconds.
- 15       9. The method according to claim 8, wherein, after performing step (e), a microstructure of the steel is composed of ferrite, needle-shaped residual austenite, a martensite/austenite composite structure, and block-shaped martensite; and  
an area fraction of the ferrite is 30 to 60 %, an area fraction of the needle-shaped residual austenite is 5 to 12 %, an area fraction of the martensite/austenite composite structure is 25 to 50 %, and an area fraction of the block-shaped martensite is 5 to 12 %.

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FIG. 1

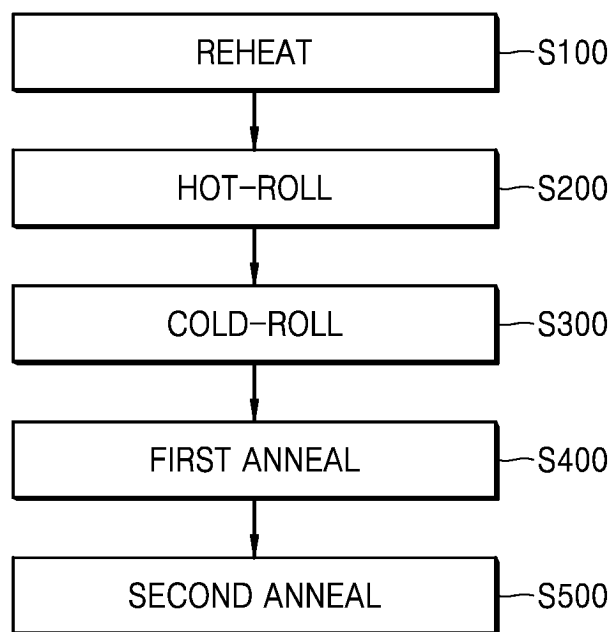


FIG. 2

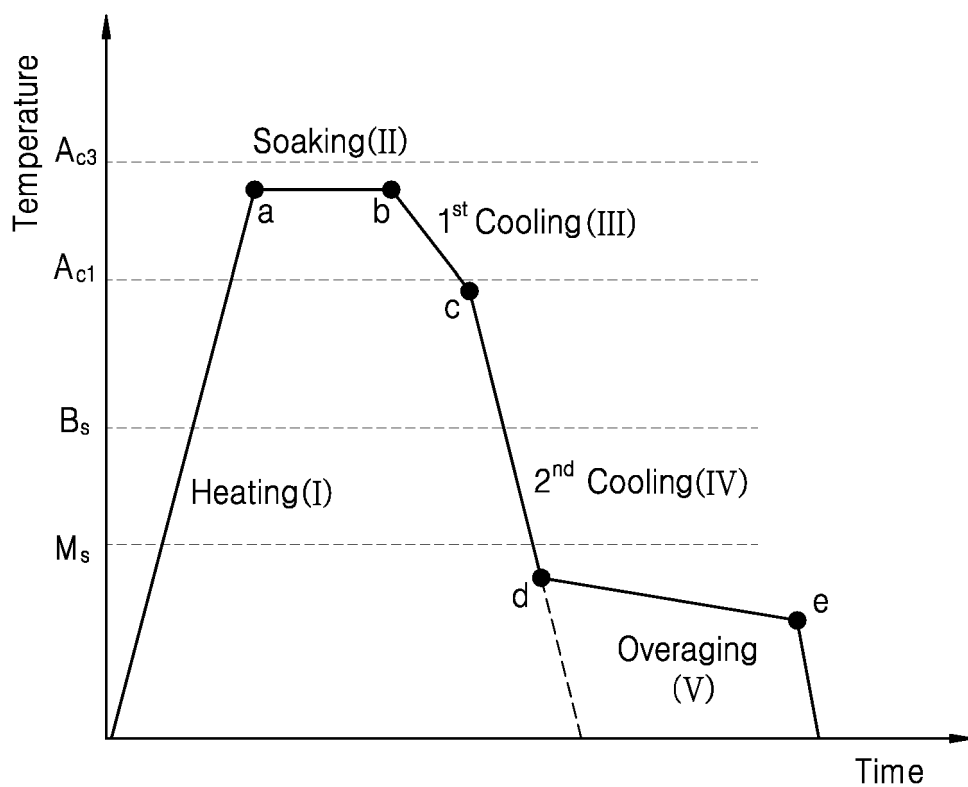
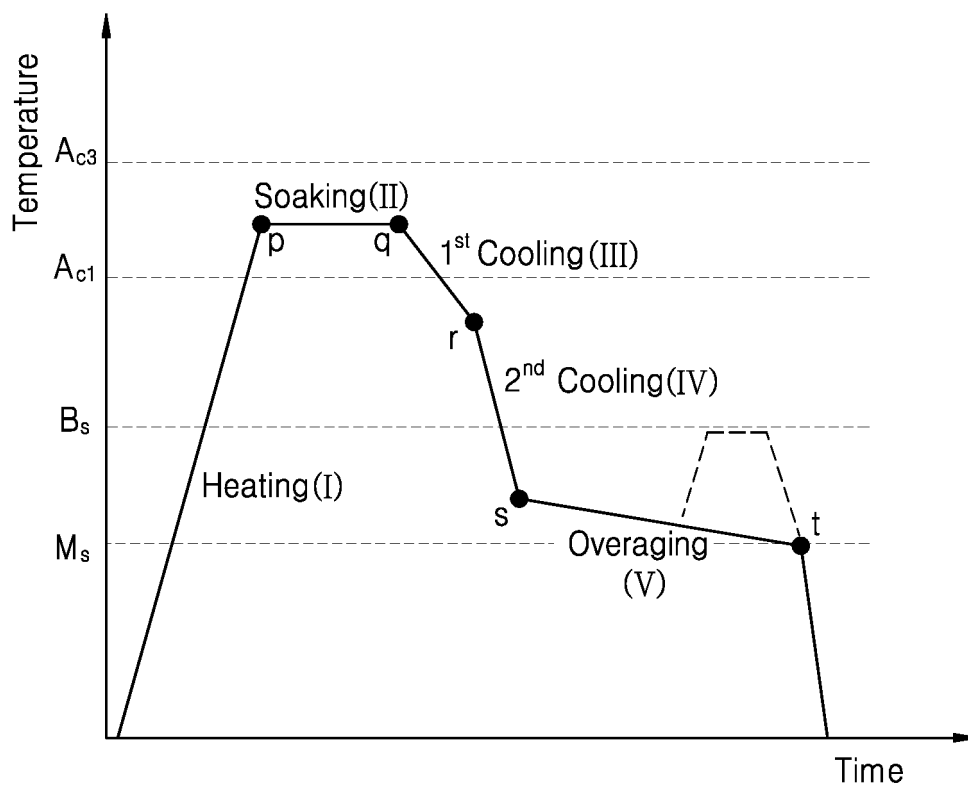
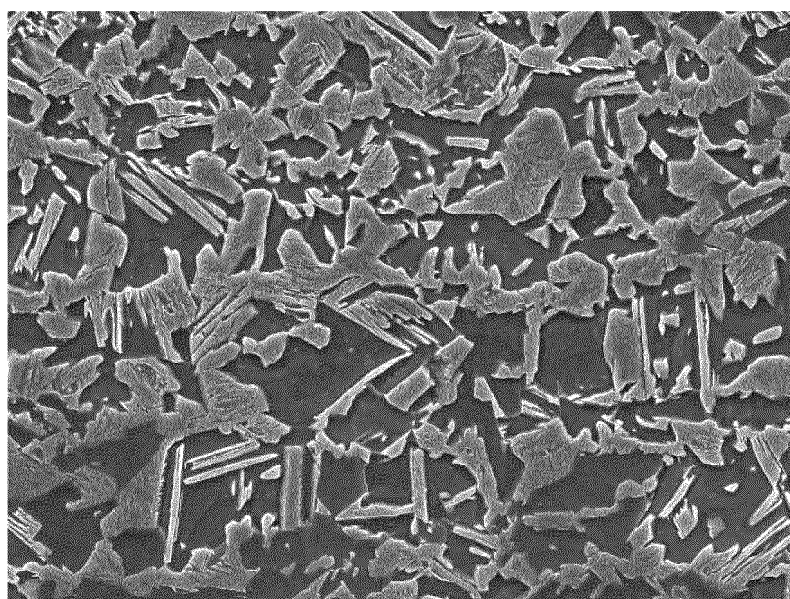
(a) 1<sup>st</sup> Annealing(b) 2<sup>nd</sup> Annealing

FIG. 3



1µm

FIG. 4

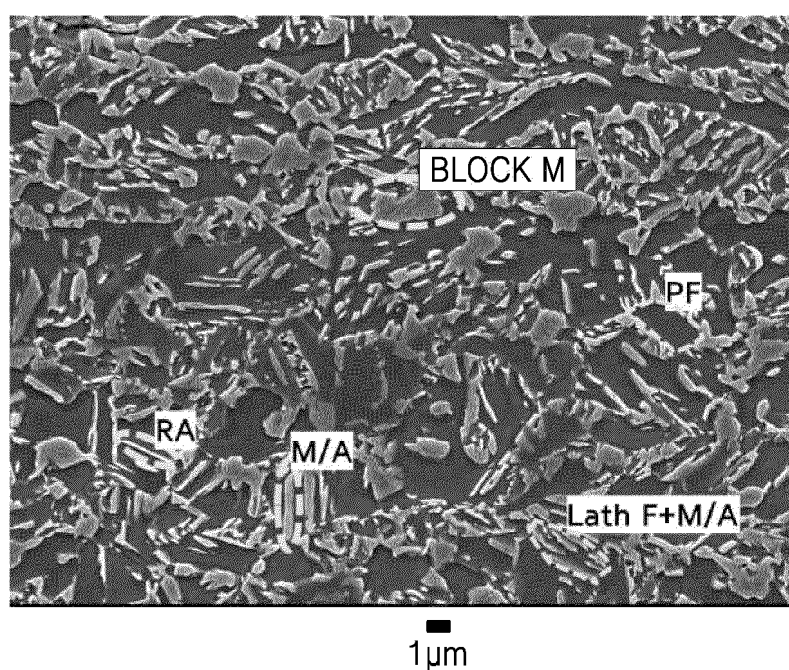
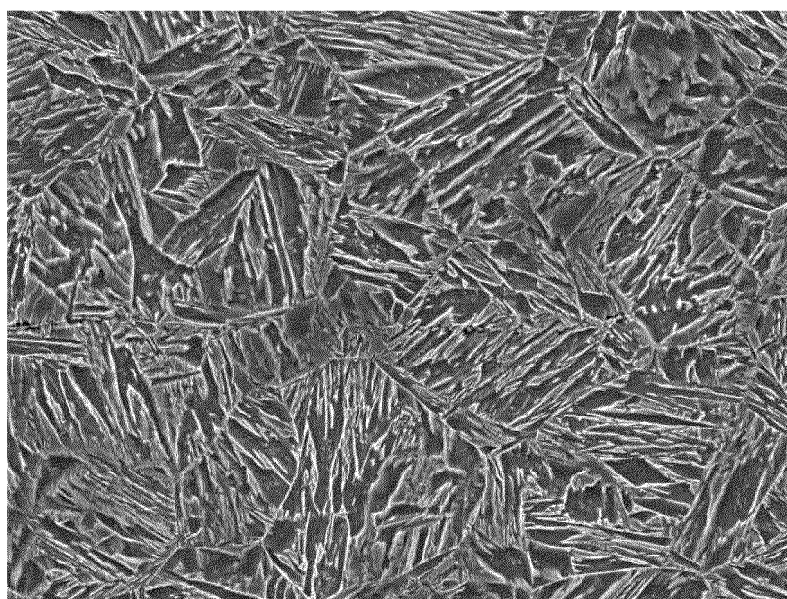


FIG. 5



1  $\mu$ m

FIG. 6

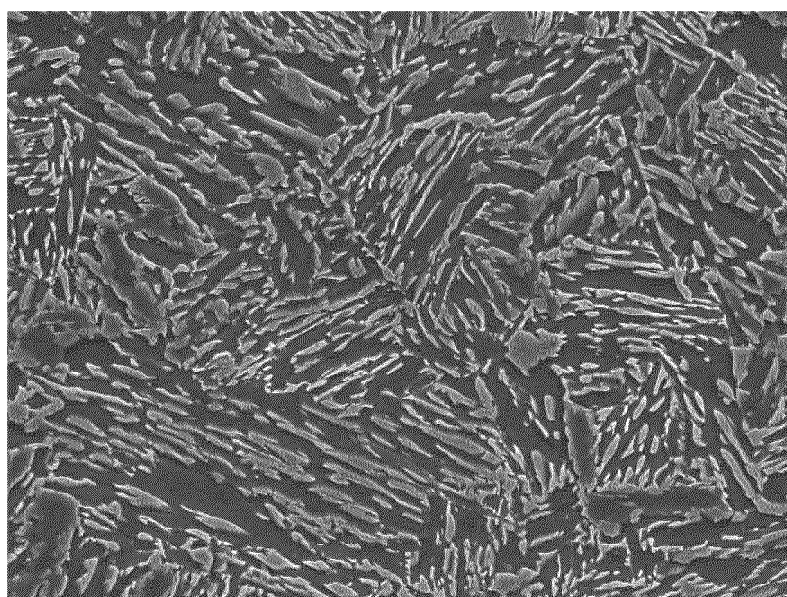


FIG. 7

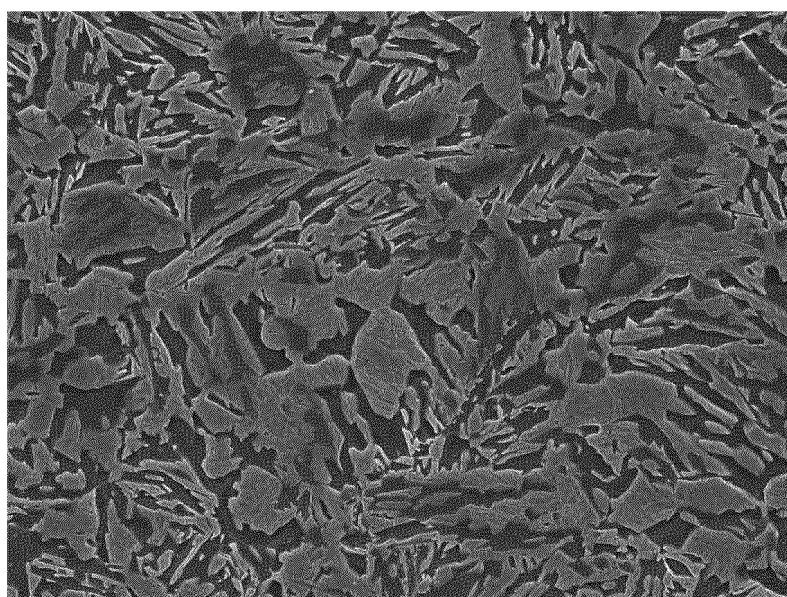


FIG. 8

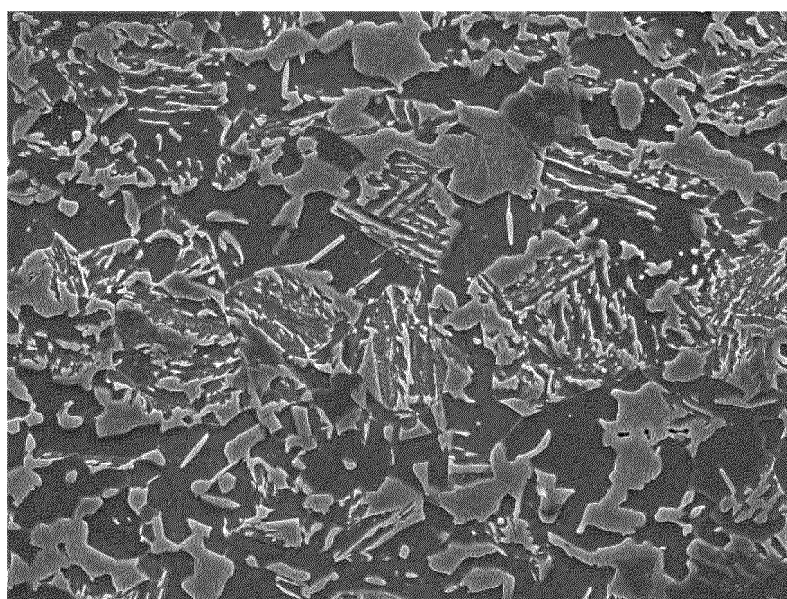
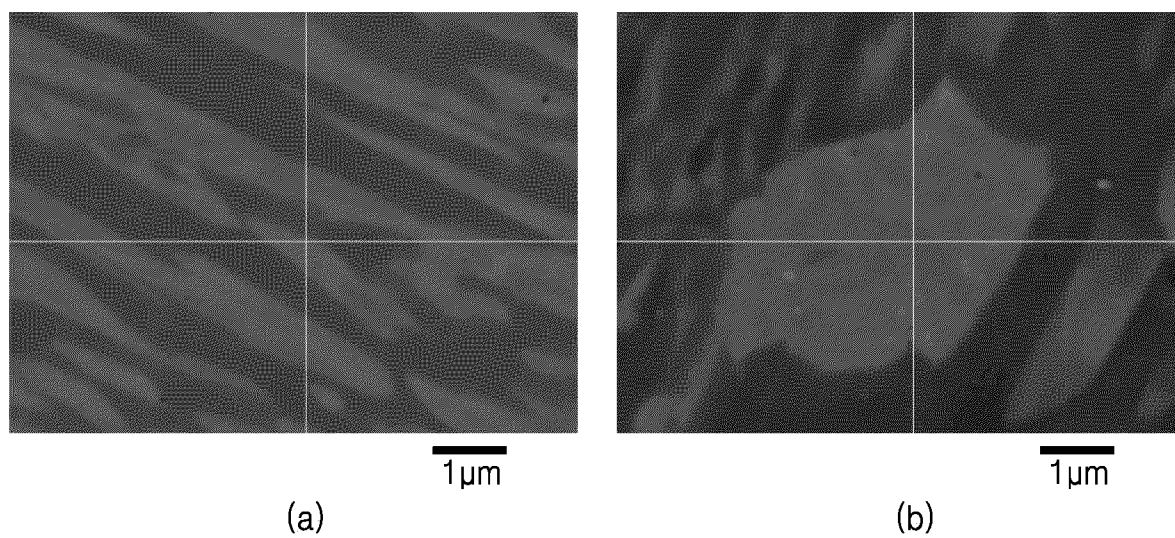




FIG. 9



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2022/019627

**A. CLASSIFICATION OF SUBJECT MATTER**

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

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/04(2006.01); C21D 8/02(2006.01); C22C 38/00(2006.01); C22C 38/06(2006.01); C22C 38/38(2006.01);  
 C22C 38/60(2006.01)

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

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

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

eKOMPASS (KIPO internal) & keywords: 냉연 강판(cold-rolled steel sheet), 페라이트(ferrite), 오스테나이트(austenite), 마르텐사이트(martensite), 고강도(high strength), 고연신율(high elongation)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KR 10-2015-0130612 A (POSCO) 24 November 2015 (2015-11-24) See claims 1, 3 and 9 and figure 1.	1-9
A	KR 10-2372546 B1 (HYUNDAI STEEL COMPANY) 10 March 2022 (2022-03-10) See paragraphs [0063], [0075] and [0079] and claim 1.	1-9
A	WO 2022-086050 A1 (POSCO) 28 April 2022 (2022-04-28) See claims 1-4 and 6.	1-9
A	KR 10-2021-0032499 A (JFE STEEL CORPORATION) 24 March 2021 (2021-03-24) See paragraph [0082] and claims 1 and 3.	1-9
A	JP 2013-540901 A (THYSSENKRUPP STEEL EUROPE A.G.) 07 November 2013 (2013-11-07) See claims 1 and 14.	1-9

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

☒ See patent family annex.

* Special categories of cited documents:	"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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"D" document cited by the applicant in the international application	"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
"E" earlier application or patent but published on or after the international filing date	"&" document member of the same patent family
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search <b>10 March 2023</b>	Date of mailing of the international search report <b>10 March 2023</b>
Name and mailing address of the ISA/KR <b>Korean Intellectual Property Office Government Complex-Daejeon Building 4, 189 Cheongsaro, Seo-gu, Daejeon 35208</b>	Authorized officer
Facsimile No. <b>+82-42-481-8578</b>	Telephone No.

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**INTERNATIONAL SEARCH REPORT**  
**Information on patent family members**

International application No.

**PCT/KR2022/019627**

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