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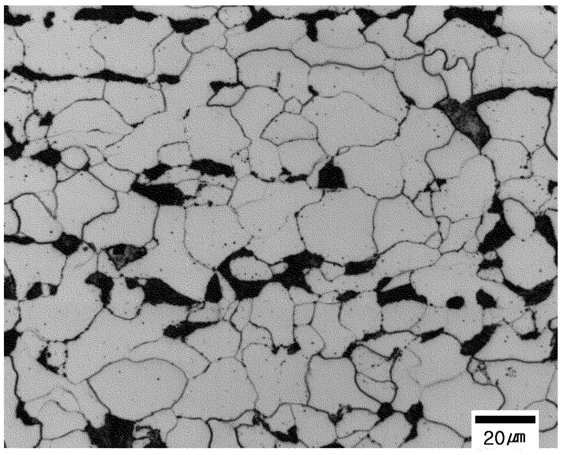
(54) HOT-ROLLED STEEL FOR HYPER TUBE AND MANUFACTURING METHOD THEREFOR

(57) An aspect of the present invention may provide: a hot-rolled steel sheet that is excellent in terms of yield strength, vibration damping ratio, weldability, and weld site-low temperature toughness and thus has physical properties suitable for use in a hyper tube; and a manufacturing method therefor.

FIG. 3



Description

Technical Field

[0001] The present disclosure relates to a hot-rolled steel sheet and a manufacturing method therefor, and more specifically, to a hot-rolled steel sheet having properties suitable for a vacuum train tube, and a manufacturing method therefor.

Background Art

[0002] A vacuum train, also known as a hyperloop train, may be a system in which a magnetically levitated train moves inside a vacuum tube. Such a train is capable of operating at an ultra-high speed because there is no friction with air or a track, which is the main cause of energy loss when running a train. Such a vacuum train may have low energy loss to conserve 93% of energy, as compared to an airplane, and may thus be in the spotlight as an eco-friendly next-generation means of transportation, and active research thereon is being conducted around the world.

[0003] A structure and material of the vacuum tube used in such a high-speed vacuum train may affect performance and costs of the system. Currently, there are three main types of materials being studied as tube materials for vacuum trains. A first material thereamong may be a concrete material. A concrete tube is advantageous in terms of costs, but individual tubes of about 10 meters in length may not be easy to be interconnected. In addition, there may be a disadvantage that, when a vacuum is created due to pores in the concrete tube, external gas may enter the tube, and the vacuum may be easily broken. A second material thereamong, which is attracting a lot of research, may be a composite material such as a carbon fiber or the like. The composite material such as a carbon fiber or the like may be light and have high performance, but high costs may be considered as the biggest disadvantage thereof.

[0004] Currently, a third material, which may be most promising for the vacuum train tube, may be steel materials. -Steel materials may be materials that may be mass-produced at low cost. Steel materials may be materials that have high rigidity and strength and are easy to process. Steel materials may be also materials that are easy to assemble or weld a component between tubes or to a tube, and have an appropriate outgassing rate when maintaining a vacuum. However, because ultra-high-speed vacuum trains operate at significantly faster speeds than current high-speed trains, safety of passengers and surrounding facilities should be considered a top priority. Currently, safety standards for ultra-high-speed vacuum trains have not been established, and development of materials for tubes to ensure safety of ultra-high-speed vacuum trains may be also insufficient. In addition, while the vacuum trains should also ensure high efficiency to match the trends of the times, the development of materials for tube to maximize energy efficiency of the vacuum trains may be also insufficient.

[0005] Therefore, there is an urgent need to develop a material for vacuum train tubes that may achieve high efficiency while ensuring processability and safety suitable for the vacuum train tubes.

[Prior Art Document(s)]

[0006] (Patent Document 1) Korean Patent No. 10-2106353 (May 4, 2020)

Summary of Invention

Technical Problem

[0007] The present disclosure seeks to provide a hot-rolled steel sheet for a vacuum train tube having excellent structural stability, and a manufacturing method therefor.

[0008] The present disclosure is to provide a hot-rolled steel sheet for a vacuum train tube maximizing energy efficiency of a vacuum train, and a manufacturing method therefor.

[0009] Objects of the present disclosure are not limited to those described above. A person skilled in the art will have no difficulty in understanding the additional problems of the present disclosure from an overall content of the present specification.

Solution to Problem

[0010] According to an aspect of the present disclosure, a hot-rolled steel sheet for a vacuum train tube includes, by weight, carbon (C): 0.03 to 0.11%, silicon (Si): 1.0 to 2.0%, manganese (Mn): 1.2 to 2.2%, a balance of Fe, and inevitable impurities, wherein a microstructure comprises a composite structure in which pearlite is dispersed in a matrix structure of ferrite.

[0011] An average particle size (D_F, pm) of the ferrite and an average aspect ratio (A_F) of the ferrite may satisfy the following relational expression 1:

[Relational expression 1]

$$7 \leq D_F/A_F \leq 20$$

[0012] The average particle size (D_F) of the ferrite may satisfy a range of 8 to 20 μm.
[0013] The average aspect ratio (A_F) of the ferrite may be 2 or less.
[0014] An amount of carbon (C) of the hot-rolled steel sheet may be 0.05 to 0.09 wt%.
[0015] An amount of silicon (Si) of the hot-rolled steel sheet may be 1.4 to 1.8 wt%.
[0016] An amount of manganese (Mn) of the hot-rolled steel sheet may be 1.5 to 1.9 wt%.
[0017] A total amount of titanium (Ti), niobium (Nb), and vanadium (V), inevitably included in the hot-rolled steel sheet, may be less than 0.01% (including 0%).
[0018] The hot-rolled steel sheet may include one or more selected from chromium (Cr), nickel (Ni), copper (Cu), molybdenum (Mo), and tungsten (W), in a total amount of 1.0% or less (including 0%).
[0019] The hot-rolled steel sheet may satisfy any one or more of the following relational expressions 2 to 5 for the hot-rolled steel sheet:

[Relational expression 2]

$$355 \leq 11 + 394*D_F^{(-0.5)} + 448*[C] + 94*[Si] + 69*[Mn]$$

$$100 \leq 186 - 240*D_F^{(-0.5)} - 121*[C] - 13.2*[Si] + 13.7*[Mn]$$ [Relational expression 3]

[0020]

[Relational expression 4]

$$27 \leq 476 - 95.22*\ln(D_F) - 220*[C] - 88*[Si]$$

[Relational expression 5]

$$35 \leq 9.5 + 5.2*[C] + 5.8*[Mn] + 13.1*[Si]$$

[0021] In Relational expressions 2 to 5, D_F is an average particle size (pm) of ferrite included in the hot-rolled steel sheet, [C], [Si], and [Mn] are an amount of carbon (C), an amount of silicon (Si), and an amount of manganese (Mn), included in the hot-rolled steel sheet (wt%), and, when a component thereamong is not included, brackets including the component are substituted with zero (0).
[0022] The microstructure of the hot-rolled steel sheet may comprise 60 to 90 area% of ferrite, 10 to 40 area% of pearlite, and an inevitable structure.
[0023] Yield strength of the hot-rolled steel sheet may be 350 MPa or more, and a Charpy impact energy of the hot-rolled steel sheet at -20°C may be 27 J or more.
[0024] A vibration damping ratio measured at a frequency of 1650Hz in a flexural vibration mode, after processing the hot-rolled steel sheet into a specimen with a length*width*thickness of 80mm*20mm*2mm, may be $100*10^{-6}$ or more.
[0025] An electrical resistivity of the hot-rolled steel sheet may be $35*10^{-8}$ Qm or more.
[0026] A yield ratio in a direction, parallel to a rolling direction of the hot-rolled steel sheet, may be 0.8 or less, and a yield ratio difference (ΔYR) in each direction, defined by the following relational expression 6, may be 10% or less:

[Relational expression 6]

$$\Delta YR = (|YR_{RD} - YR_{TD}| * 100) / YR_{RD}$$

[0027] In the above relational expression 6, YR_{RD} is a yield ratio in a direction, parallel to a rolling direction of the hot-rolled steel sheet, YR_{TD} is a yield ratio in a direction, perpendicular to the rolling direction of the hot-rolled steel sheet, and $|YR_{RD} - YR_{TD}|$ is an absolute value of a difference between the yield ratio (YR_{RD}) in a direction, parallel to the rolling direction and the yield ratio (YR_{TD}) in a direction, perpendicular to the rolling direction.

[0028] In a welded portion formed by welding the hot-rolled steel sheet using submerged arc welding, a Charpy impact energy of the welded portion at -20°C may be 27 J or more, and a fraction of an M-A phase included in the welded portion may be 5 area% or less (including 0%).

[0029] A thickness of the hot-rolled steel sheet may be 10 mm or more.

[0030] According to an aspect of the present disclosure, a method for manufacturing a hot-rolled steel sheet for a vacuum train tube, includes heating a slab to a heating temperature (T_1) of 1100°C to 1300°C, wherein the slab includes, by weight, carbon (C) : 0.03 to 0.11%, silicon (Si): 1.0 to 2.0%, manganese (Mn): 1.2 to 2.2%, a balance of Fe, and inevitable impurities; hot-rolling the heated slab at a finish rolling temperature (T_2) of 900°C to 1000°C to provide a hot-rolled steel sheet; and coiling the hot-rolled steel sheet at a coiling temperature (T_3) of 600°C to 700°C, wherein the finish rolling temperature (T_2) and the coiling temperature (T_3) satisfy the following relational expression 7:

$$10 \leq -101.9 + 0.103*[T_2] + 0.0339*[T_3] - 61.9*[C] - 190.2*[Nb] \leq 20 \quad \text{[Relational expression 7]}$$

[0031] In Relational expression 7, $[T_2]$ and $[T_3]$ are the finish rolling temperature (T_2, °C) and the coiling temperature (T_3, °C), [C] and [Nb] are an amount of carbon (C) and an amount of niobium (Nb), included in the hot-rolled steel sheet (wt%), and, when a component thereamong is not included, brackets including the component are substituted with zero (0).

[0032] An amount of carbon (C) of the slab may be 0.05 to 0.09 wt%.

[0033] An amount of silicon (Si) of the slab may be 1.4 to 1.8 wt%.

[0034] An amount of manganese (Mn) of the slab may be 1.5 to 1.9 wt%.

[0035] A total amount of titanium (Ti), niobium (Nb), and vanadium (V), inevitably included in the slab, may be less than 0.01% (including 0%).

[0036] The slab may include one or more selected from chromium (Cr), nickel (Ni), copper (Cu), molybdenum (Mo), and tungsten (W), in a total amount of 1.0% or less (including 0%) .

[0037] A thickness of the hot-rolled steel sheet may be 10 mm or more.

[0038] Means for solving the above problems does not list all features of the present disclosure, and various features of the present disclosure and advantages and effects thereof will be understood in more detail with reference to specific embodiments and embodiments below.

Advantageous Effects of Invention

[0039] According to an aspect of the present disclosure, a hot-rolled steel sheet having excellent yield strength, yield ratio, vibration damping ratio, and low-temperature toughness, and low anisotropy of the yield ratio, which has physical properties suitable for vacuum train tubes, and a method for manufacturing the same, may be provided.

[0040] Effects of the present disclosure are not limited to the above, and may be construed as including matters reasonably inferred by those skilled in the art from matters described in the present specification.

Brief Description of Drawings

[0041]

FIG. 1 is a micrograph observing a welded portion formed by welding a base material containing 1.5 wt% of silicon (Si) using a welding material not containing silicon (Si) .

FIG. 2 is a micrograph observing a welded portion formed by welding a base material containing 2.0 wt% of silicon (Si) using a welding material containing 0.3 wt% of silicon (Si).

FIG. 3 is an optical micrograph used to observe a microstructure of specimen 1.

FIG. 4 is an optical micrograph of EN-S355, a conventional structural steel material.

Best Mode for Invention

[0042] The present disclosure relates to a hot-rolled steel sheet for a vacuum train tube and a manufacturing method therefor, and hereinafter, preferred embodiments of the present disclosure will be described. Embodiments of the present disclosure may be modified in various forms, and the scope of the present disclosure should not be construed as being limited to embodiments described below. The present embodiments may be provided to describe the present disclosure in more detail to those skilled in the art to which the present disclosure pertains.

[0043] A vacuum train may be a train that runs inside a tube in a vacuum or sub-vacuum state, and may be a next-generation transportation vehicle currently in an early stage of development. The vacuum train may be a means of transportation that may effectively achieve high speed and high efficiency by eliminating frictional resistance between wheels and tracks and minimizing air resistance. However, due to nature of the vacuum train operating at ultra-high speeds, there may be a risk of large-scale accidents occurring when safety of the vacuum train is not sufficiently secured. In particular, not only when the vacuum tube is structurally damaged or collapsed, but also when a partial shape of the tube is deformed, a large-scale disaster may occur. Therefore, a material for a vacuum train tube requires more stringent safety measures. As a result of in-depth research, the inventor of the present disclosure found that the following characteristics are important as a material for the vacuum tube to ensure safety of the vacuum train.

[0044] It is desirable that a material for the vacuum tube has high strength characteristics. Since the vacuum train moves through an internal space of the vacuum tube, the material for vacuum tube may be required to have sufficient strength as a structure. Additionally, since the internal space of the vacuum tube should be maintained in a vacuum or sub-vacuum state, it is required to have sufficient strength characteristics to prevent a shape of the tube from being deformed due to a difference in pressure between the internal space and an external space.

[0045] It is desirable that the material for vacuum tube has excellent vibration damping ability. In the vacuum train, a pod in which several dozen people are on board may pass through the internal space of the vacuum tube at intervals of tens of seconds to several minutes. When passing a preceding pod and then passing a succeeding pod, vibration may be amplified within the vacuum tube, causing resonance, and in serious cases, it may even cause damage to the tube. Therefore, when a material having a vibration damping ratio above a certain level is applied to the vacuum tube, vibration within the tube may be effectively reduced after passing the preceding pod, and may effectively contribute to safety of the vacuum train.

[0046] It is desirable that the material for vacuum tube has excellent low-temperature toughness. The vacuum train may also operate in polar regions or deep oceans. Iron and steel materials tend to be more easily damaged in a low-temperature environment or an extremely low-temperature environment. Therefore, when iron and steel are applied to the vacuum tube, it is required to have a certain level of low-temperature toughness to ensure safety. In particular, since a tube for the vacuum train is manufactured to have a tube shape by welding, excellent low-temperature toughness may be required not only in a base material but also in a welded portion.

[0047] It is desirable that the material for vacuum tube has excellent buckling resistance and earthquake resistance properties. A compressive load may be applied to the vacuum tube along a length of the vacuum tube due to operation of the vacuum train or influence of a surrounding environment. When the compressive load applied to the vacuum tube exceeds a critical load, buckling, a phenomenon in which the vacuum tube suddenly bends in a direction, perpendicular to a load direction, may occur. Additionally, when an earthquake of a certain magnitude or higher occurs in a region in which the vacuum tube is installed, the vacuum tube may be structurally damaged or collapse. Therefore, the material for vacuum tube may be required to have excellent buckling resistance and earthquake resistance properties to ensure structural safety, and such properties may be secured by lowering the yield ratio of the material. When a yield ratio of the material is anisotropic, the vacuum tube may be easily damaged or bent, even when a load significantly lower than the critical load is applied to the vacuum tube in a specific direction. Therefore, it is advantageous for the material for vacuum tubes to have a low yield ratio and have a small deviation in yield ratio value depending on a direction.

[0048] It is desirable that the material for vacuum tube have excellent electrical resistivity. The vacuum train may minimize friction between a track and a train through magnetic levitation, and the methods of levitating the train may be broadly divided into an electromagnetic suspension (EMS) method and an electrodynamic suspension (EDS) method. The electromagnetic suspension (EMS) method may use attractive force between (electro)magnets to levitate the train, and the electrodynamic suspension (EDS) method may use repulsive force between a superconductor and a magnet. Both the electrodynamic suspension (EDS) method and the electromagnetic suspension (EMS) method may form a strong magnetic field around the vacuum train, which is running, and a change in magnetic field, as above, may form an induced current in the vacuum tube. Since generation of such induced current means energy loss, it is necessary to reduce such energy loss by increasing electrical resistivity of the material for vacuum tube.

[0049] Through in-depth research, the inventor of the present disclosure strictly controlled alloy composition amounts and a microstructure of the steel sheet, to improve yield strength, a yield ratio, a vibration damping ratio, low-temperature toughness, and electrical resistivity, and lower anisotropy of the yield ratio. After recognizing this, the present disclosure was developed.

[0050] Hereinafter, a hot-rolled steel sheet for a vacuum train tube according to an aspect of the present disclosure will be described in more detail.

[0051] A hot-rolled steel sheet for a vacuum train tube includes, by weight, carbon (C) : 0.03 to 0.11%, silicon (Si): 1.0 to 2.0%, manganese (Mn): 1.2 to 2.2%, a balance of Fe, and inevitable impurities, wherein a composite structure in which pearlite is dispersed in a matrix structure of ferrite is included as a microstructure.

[0052] Hereinafter, the steel composition included in the hot-rolled steel sheet according to an aspect of the present disclosure will be described in more detail. Hereinafter, unless specifically described, % described in relation to an amount of each element is based on a weight.

Carbon (C): 0.03 to 0.11%

[0053] Carbon (C) may be a component that has a very large impact on strength of a steel sheet. The present disclosure may include 0.03% or more of carbon (C) to ensure strength required for a structure. A preferable lower limit of the amount of carbon (C) may be 0.04%, and a more preferable lower limit of the amount of carbon (C) may be 0.05%. When the carbon (C) content is excessive, toughness of the material may decrease, weldability may deteriorate, and a yield ratio may increase. In addition, when an amount of carbon (C) is excessive, it may be difficult to coarsen crystal grains. Therefore, the present disclosure limits an upper limit of the amount of carbon (C) to 0.11%. A preferable upper limit of the amount of carbon (C) is 0.10%, and a more preferable upper limit of the amount of carbon (C) is 0.09%.

Silicon (Si): 1.0 to 2.0%

[0054] Since silicon (Si) may combine with oxygen to form a slag in steelmaking, silicon (Si) tends to be removed along with oxygen. Additionally, silicon (Si) may be also a component that effectively contributes to improving strength of a material. Therefore, the present disclosure may include 1.0% or more of silicon (Si) for this effect. A preferable lower limit of the amount of silicon (Si) is 1.2%, and a more preferable lower limit of the amount of silicon (Si) is 1.4%. When silicon (Si) content is excessive, removal of a surface scale may be prevented, and a surface quality of a product may be reduced. In addition, when an amount of silicon (Si) is excessive, low-temperature toughness of a welded portion may be reduced by promoting formation of an M-A phase (a martensite-austenite complex) in the welded portion, the present disclosure may limit an amount of silicon (Si) to 2.0% or less. A preferable upper limit of the amount of silicon (Si) is 1.9%, and a more preferable upper limit of the amount of silicon (Si) is 1.8%.

Manganese (Mn): 1.2 to 2.2%

[0055] Manganese (Mn) may be a component that improves strength and hardenability of steel. Therefore, the present disclosure may include 1.2% or more of manganese (Mn) to ensure this effect. A preferable lower limit of the amount of manganese (Mn) is 1.3%, and a more preferable lower limit of the amount of manganese (Mn) is 1.5%. When an amount of manganese (Mn) is excessive, material deviation may occur due to segregation in a central portion, and crack propagation resistance may be poor. In addition, when the amount of manganese (Mn) is excessive, toughness of the steel may decrease. Therefore, in the present disclosure, the amount of manganese (Mn) is limited to 2.2% or less. A preferable upper limit of the amount of manganese (Mn) is 2.1%, and a more preferable upper limit of the amount of manganese (Mn) is 1.9%.

[0056] The hot-rolled steel sheet according to an aspect of the present disclosure may further include one or more selected from chromium (Cr), nickel (Ni), copper (Cu), molybdenum (Mo), and tungsten (W), in addition to the above-described alloy components. One or more components selected from chromium (Cr), nickel (Ni), copper (Cu), molybdenum (Mo), and tungsten (W) may contribute to improving the strength of the hot-rolled steel sheet. When the above component is added excessively, not only a carbon equivalent (Ceq) may be excessively high, but also costs therefrom may increase. A total amount of one or more selected from chromium (Cr), nickel (Ni), copper (Cu), molybdenum (Mo), and tungsten (W) may be 1.0% or less. The total amount of one or more selected from chromium (Cr), nickel (Ni), copper (Cu), molybdenum (Mo), and tungsten (W) may be 0.5%, and cases in which the total amount of the components is 0% may be included.

[0057] A hot-rolled steel sheet according to an aspect of the present disclosure may include a remaining Fe and other inevitable impurities in addition to the above-mentioned components. In a typical manufacturing process, unintended impurities from raw materials or surrounding environment may be inevitably mixed, and thus this may not be entirely excluded. Since all of these impurities may be known to anyone skilled in the art, all of the contents may not be specifically mentioned in the present specification. In addition, additional components effective in addition to the above-described components may not be entirely excluded.

[0058] A hot-rolled steel sheet according to an aspect of the present disclosure may actively suppress addition of titanium (Ti), niobium (Nb), and vanadium (V), and even when these components are inevitably included, the total amount thereof may limit less than 0.01% (including 0%). Titanium (Ti), niobium (Nb), and vanadium (V) may be representative precipitation strengthening elements that effectively contribute to improving strength of steel by generating fine carbon-itrides. Since titanium (Ti), niobium (Nb), and vanadium (V) may excessively refine a microstructure of the steel, which may be detrimental to securing vibration damping ability, the present disclosure is seeks to actively suppress these components. Additionally, titanium (Ti), niobium (Nb), and vanadium (V) may be expensive components, and may be undesirable from an economic perspective. The present disclosure may not artificially add these components, and even when they are unavoidably added, the total amount of these components may be actively suppressed to be less than 0.01%. Preferably, the total amount of these components is 0.005% or less, and more preferably, the total amount of these components is 0%.

[0059] Hereinafter, a microstructure of a hot-rolled steel sheet according to an aspect of the present disclosure will be described in more detail.

[0060] A hot-rolled steel sheet according to an aspect of the present disclosure may have a composite structure in which pearlite is dispersed in a matrix structure of ferrite as a microstructure. In this case, the matrix structure may be interpreted to mean a structure that occupies 50 area% or more, when observing the microstructure of the hot-rolled steel sheet.

[0061] A hot-rolled steel sheet according to an aspect of the present disclosure may actively suppress creation of low-temperature structures such as bainite, martensite, or the like. A steel sheet having a low-temperature structure such as bainite, martensite, or the like may have high strength and a low yield ratio, and may thus exhibit excellent properties as a structural material. Since a hot-rolled steel sheet for a vacuum train tube targeted by the present disclosure may be thick at a level of 10 mm or more, a low-temperature structure may be formed only on a surface of the steel sheet, and it may be difficult to sufficiently generate the low-temperature structure up to a central portion of the steel sheet. Therefore, in the present disclosure, to suppress the occurrence of property deviation in a thickness direction of the steel sheet, even when the microstructure of the steel sheet includes a composite structure in which pearlite is dispersed in a matrix structure of ferrite, and a low-temperature structure such as bainite, martensite, or the like is inevitable, a fraction thereof may be actively suppressed to 1 area% or less (including 0%). In terms of securing properties, a fraction of ferrite may be 60 to 90 area%, and a fraction of pearlite may be 10 to 40 area%.

[0062] To simultaneously secure desired yield strength, vibration damping ratio, and low-temperature toughness, the present disclosure may limit an average particle size (D_F, pm) of ferrite to a certain range. As a grain size increases, it may be more advantageous to secure the vibration damping ratio. Therefore, the present disclosure may limit the average particle size (D_F, pm) of ferrite to 8 pm or more. When the grain size is excessively large, strength and low-temperature toughness of a material may deteriorate. Therefore, the present disclosure may limit the average particle size (D_F, pm) of ferrite to 20 pm or less.

[0063] As a result of conducting in-depth research on ways to ensure stability of a material for a vacuum train tube, the inventor of the present disclosure found that a ratio of the average particle size (D_F, pm) of ferrite to an average aspect ratio (A_F) of ferrite was within a certain range. It was confirmed that the material anisotropy of the material could be effectively reduced when adjusted to, and the relational expression 1 below was derived.

[Relational expression 1]

$$7 \leq D_F/A_F \leq 20$$

[0064] In Relational expression 1, D_F means an average particle size (μm) of ferrite included in the hot-rolled steel sheet, and A_F means an average aspect ratio of ferrite.

[0065] In addition, the inventor of the present disclosure found that, when controlling amounts of carbon (C), silicon (Si), and manganese (Mn), and the average particle size (DF, pm) of ferrite within a certain range in a low-alloy steel sheet such as the present disclosure, recognizing that it is possible to simultaneously secure yield strength, vibration damping ratio, and low-temperature toughness of the welded portion, Relational expressions 2 to 4 below were derived.

[Relational expression 2]

$$355 \leq 11 + 394*D_F^{(-0.5)} + 448*[C] + 94*[Si] + 69*[Mn]$$

$$100 \leq 186 - 240*D_F^{(-0.5)} - 121*[C] - 13.2*[Si] + 13.7*[Mn] \quad \text{[Relational expression 3]}$$

[Relational expression 4]

$$27 \leq 476 - 95.22*\ln(D_F) - 220*[C] - 88*[Si]$$

[0066] In Relational expressions 2 to 4, D_F is an average particle size (pm) of ferrite included in the hot-rolled steel sheet, [C], [Si], and [Mn] are an amount of carbon (C), an amount of silicon (Si), and an amount of manganese (Mn), included in the hot-rolled steel sheet (wt%), and, when a component thereamong is not included, brackets including the component are substituted with zero (0).

[0067] In addition, the inventor of the present disclosure found that, when controlling relative amounts of carbon (C), silicon (Si), and manganese (Mn) within a certain range in a low-alloy steel sheet such as the present disclosure, recognizing that it is possible to improve electrical resistivity, Relational expression 5 below was derived.

[Relational expression 5]

$$35 \leq 9.5 + 5.2*[C] + 5.8*[Mn] + 13.1*[Si]$$

[0068] In Relational expressions 2 to 5, D_F is an average particle size (pm) of ferrite included in the hot-rolled steel sheet, [C], [Si], and [Mn] are an amount of carbon (C), an amount of silicon (Si), and an amount of manganese (Mn), included in the hot-rolled steel sheet (wt%), and, when a component thereamong is not included, brackets including the component are substituted with zero (0).

[0069] A hot-rolled steel sheet for a vacuum train tube according to an aspect of the present disclosure may satisfy any one or more of the above-described alloy component amounts and relational expressions 1 to 5, and thus a desired level of yield strength, yield ratio, material anisotropy, base material low-temperature toughness, vibration damping ratio, electrical resistivity, and low-temperature toughness of the welded portion may be secured.

[0070] A hot-rolled steel sheet for a vacuum train tube according to an aspect of the present disclosure may have a yield strength of 350 MPa or more and a Charpy impact energy at -20°C of 27 J or more. Therefore, the hot-rolled steel sheet for a vacuum train tube of the present disclosure may secure suitable strength and low-temperature toughness as a structural material, and may effectively ensure the structural safety of the vacuum train tube.

[0071] A hot-rolled steel sheet for a vacuum train tube according to an aspect of the present disclosure may have a vibration damping ratio of $100*10^{-6}$ or more. In this case, the vibration damping ratio refers to a vibration damping ratio measured at a frequency of 1650 Hz, after hitting a specimen with a length*width*thickness of 80mm*20mm*2mm in a flexural vibration mode. Since a hot-rolled steel sheet for a vacuum train tube according to an aspect of the present disclosure may have a vibration damping ratio of $100*10^{-6}$ or more, vibration amplification in the vacuum tube may be effectively suppressed, and damage to the vacuum train tube due to vibration may be prevented effectively.

[0072] A hot-rolled steel sheet for a vacuum train tube according to an aspect of the present disclosure may have an electrical resistivity of $35*10^{-8}$ Ωm or more, and energy efficiency may be effectively secured, when operating the vacuum train.

[0073] A hot-rolled steel sheet for a vacuum train tube according to an aspect of the present disclosure has a yield ratio of 0.8 or less, and a yield ratio difference (ΔYR) in each direction, defined by the following relational expression 6, may be 10% or less. For example, A hot-rolled steel sheet for a vacuum train tube according to an aspect of the present disclosure has a low yield ratio characteristic while suppressing material anisotropy as much as possible, and may have excellent buckling resistance and earthquake resistance characteristics.

[Relational expression 6]

$$\Delta YR = (|YR_{RD} - YR_{TD}| * 100) / YR_{RD}$$

[0074] In the above Relational expression 6, YR_{RD} is a yield ratio in a direction, parallel to a rolling direction of the hot-rolled steel sheet, YR_{TD} is a yield ratio in a direction, perpendicular to the rolling direction of the hot-rolled steel sheet, and $|YR_{RD} - YR_{TD}|$ is an absolute value of a difference between the yield ratio (YR_{RD}) in a direction, parallel to the rolling direction and the yield ratio (YR_{TD}) in a direction, perpendicular to the rolling direction.

[0075] When a hot-rolled steel sheet according to an aspect of the present disclosure is welded using submerged arc welding, a Charpy impact energy of the welded portion at - 20°C may be 27 J or more, and a fraction of an M-A phase included in the welded portion may be 5 area% or less (including 0%) . A preferable fraction of the M-A phase of the welded portion may be 3 area% or less, and a more preferable fraction of the M-A phase of the welded portion may be

1 area% or less. In this case, the welded portion may be a position 1 mm away from a fusion line, and may be interpreted to include both a weld metal portion and a heat-affected zone (HAZ).

[0076] Although a welding material used for welding in the present disclosure is not particularly limited, it is desirable to perform welding using a welding material that does not contain silicon (Si), as possible. This may be because when welding is performed using a welding material containing silicon (Si), there is a possibility that a large amount of hard M-A phase is formed in the welded portion due to excessive hardenability. FIG. 1 is a micrograph observing a welded portion formed by welding a base material containing 1.5 wt% of silicon (Si) using a welding material not containing silicon (Si), and FIG. 2 is a micrograph observing a welded portion formed by welding a base material containing 2.0 wt% of silicon (Si) using a welding material containing 0.3 wt% of silicon (Si). In FIG. 2, a large amount of white portion (M-A phase) is observed at a grain boundary, while in FIG. 1, the M-A phase is not observed.

[0077] Therefore, according to an aspect of the present disclosure, it is possible to provide a hot-rolled steel sheet having properties suitable for a vacuum train tube due to excellent yield strength, yield ratio, material anisotropy, base material low-temperature toughness, vibration damping ratio, electrical resistivity, and welded portion low-temperature toughness.

[0078] A thickness of a hot-rolled steel sheet for a vacuum train tube according to an aspect of the present disclosure is not particularly limited, but may be 10 mm or more to comply with the trend toward larger diameters of a vacuum train tube.

[0079] Hereinafter, a method for manufacturing a hot-rolled steel sheet for a vacuum train tube according to an aspect of the present disclosure will be described in more detail.

[0080] A method for manufacturing a hot-rolled steel sheet for a vacuum train tube according to an aspect of the present disclosure includes heating a slab to a heating temperature (T_1) of 1100°C to 1300°C, wherein the slab includes, by weight, carbon (C): 0.03 to 0.11%, silicon (Si): 1.0 to 2.0%, manganese (Mn): 1.2 to 2.2%, a balance of Fe, and inevitable impurities; hot-rolling the heated slab at a finish rolling temperature (T_2) of 900°C to 1000°C to provide a hot-rolled steel sheet; and coiling the hot-rolled steel sheet at a coiling temperature (T_3) of 600°C to 700°C, wherein the finish rolling temperature (T_2) and the coiling temperature (T_3) satisfy the following relational expression 7:

$$10 \leq -101.9 + 0.103*[T_2] + 0.0339*[T_3] - 61.9*[C] - 190.2*[Nb] \leq 20 \qquad \text{[Relational expression 7]}$$

[0081] In Relational expression 7, $[T_2]$ and $[T_3]$ are the finish rolling temperature (T_2, °C) and the coiling temperature (T_3, °C), [C] and [Nb] are an amount of carbon (C) and an amount of niobium (Nb), included in the hot-rolled steel sheet (wt%), and, when a component thereamong is not included, brackets including the component are substituted with zero (0).

Preparation and Heating of Steel Slab

[0082] A steel slab having a predetermined alloy composition may be prepared. Since the steel slab of the present disclosure has an alloy composition corresponding to the above-described hot-rolled steel sheet, description of the alloy composition of the steel slab may be replaced with the description of the alloy composition of the above-described hot-rolled steel sheet.

[0083] The prepared steel slab may be heated to a heating temperature (T_1) of 1100°C to 1300°C. Considering a rolling load during hot-rolling, the steel slab may be heated in a temperature range of 1100°C or higher. In particular, since the present disclosure seeks to introduce a microstructure of a certain size or more, a preferred heating temperature of the steel slab may be 1200°C or more. A more preferred heating temperature of the steel slab may be 1250°C or higher. When the heating temperature of the steel slab is excessively high, there may be concern about deterioration in surface quality due to scale formation. Therefore, the present disclosure may limit the heating temperature of the steel slab to 1300°C or lower.

Hot-Rolling

[0084] A hot-rolled steel sheet may be provided by hot-rolling the heated steel slab at a finish rolling temperature (T_2) of 900°C to 1000°C. The hot-rolled steel sheet provided by hot-rolling of the present disclosure may have a thickness of 10 mm or more.

[0085] During hot-rolling, grains may be deformed, as a material is rolled, but soon recrystallize. Through this process, coarse and uneven tissues may be fine and homogenized. An important process factor during hot-rolling may be a finishing delivery temperature (FDT), which may be a temperature in ending the rolling. This may be because the grain size of the final microstructure may be controlled depending on the finishing rolling temperature. Since the present disclosure seeks to control the final microstructure to a level above a certain size, hot-rolling may be performed at a finish rolling temperature of 900°C or higher. A preferable finish rolling temperature is 930°C or higher, and a more preferable finish rolling temperature is 950°C. When the finish rolling temperature is excessively high, the final microstructure may become excessively coarse. Therefore, the present disclosure may limit an upper limit of the finish rolling temperature to 1000°C.

Coiling

[0086] The hot-rolled steel sheet provided by hot-rolling may be coiled at a coiling temperature (T_3) of 600°C to 700°C, after undergoing water cooling. Since the present disclosure seeks to implement a composite structure of ferrite and pearlite as a final structure, coiling may be performed in a temperature range of 600°C or higher. Since the present disclosure seeks to realize a final microstructure of a certain size or more, it is more preferable to coil at a temperature range of 650°C or higher. When a temperature of the coiling is excessively high, a coarse microstructure may be formed or surface quality may deteriorate. Therefore, the present disclosure may limit an upper limit of the coiling temperature to 700°C.

[0087] The inventor of the present disclosure has conducted in-depth research on technical means for controlling a particle size of the final microstructure. To control the particle size of the final microstructure in the composition system of the present disclosure, it was confirmed that not only the heating temperature (T_1) during heating the steel slab, the finish rolling temperature (T_2) during hot-rolling, and the coiling temperature (T_3) during coiling of the hot-rolled steel sheet should be independently controlled to satisfy a certain range, but also the finish rolling temperature (T_2) and the coiling temperature (T_3) should be controlled independently within a certain range in conjunction with each other, the relational expression 7 below was then derived.

$$10 \leq -101.9 + 0.103*[T_2] + 0.0339*[T_3] - 61.9*[C] - 190.2*[Nb] \leq 20 \qquad \text{[Relational expression 7]}$$

[0088] In Relational expression 7, $[T_2]$ and $[T_3]$ are the finish rolling temperature (T_2, °C) and the coiling temperature (T_3, °C), [C] and [Nb] are an amount of carbon (C) and an amount of niobium (Nb), included in the hot-rolled steel sheet (wt%), and, when a component thereamong is not included, brackets including the component are substituted with zero (0).

[0089] Therefore, a method for manufacturing a hot-rolled steel sheet for a vacuum train tube according to an aspect of the present disclosure includes not only heating a slab to a heating temperature (T_1) of 1100°C to 1300°C, hot-rolling at a finish rolling temperature (T_2) of 900°C to 1000°C, and coiling the hot-rolled steel sheet at a coiling temperature (T_3) of 600°C to 700°C, but also controlling process conditions such that the finish rolling temperature (T_2) and the coiling temperature (T_3) satisfy relational expression 7. Therefore, a desired microstructure of the hot-rolled steel sheets may be effectively realized.

[0090] The hot-rolled steel sheet manufactured by the above-described manufacturing method may satisfy any one or more of the following relational expressions 1 to 5.

[Relational expression 1]

$$7 \leq D_F/A_F \leq 20$$

[0091] In relational expression 1, D_F means an average particle size (μm) of ferrite included in the hot-rolled steel sheet, and A_F means an average aspect ratio of ferrite.

[Relational expression 2]

$$355 \leq 11 + 394*D_F^{(-0.5)} + 448*[C] + 94*[Si] + 69*[Mn]$$

$$100 \leq 186 - 240*D_F^{(-0.5)} - 121*[C] - 13.2*[Si] + 13.7*[Mn] \qquad \text{[Relational expression 3]}$$

[Relational expression 4]

$$27 \leq 476 - 95.22*\ln(D_F) - 220*[C] - 88*[Si]$$

[Relational expression 5]

$$35 \leq 9.5 + 5.2*[C] + 5.8*[Mn] + 13.1*[Si]$$

[0092] In relational expression 1, D_F means an average particle size (μm) of ferrite included in the hot-rolled steel sheet, and A_F means an average aspect ratio of ferrite.

[0093] In relational expressions 2 to 5, D_F is an average particle size (pm) of ferrite included in the hot-rolled steel sheet, [C], [Si], and [Mn] are an amount of carbon (C), an amount of silicon (Si), and an amount of manganese (Mn), included in the hot-rolled steel sheet (wt%), and, when a component thereamong is not included, brackets including the component are substituted with zero (0).

[0094] The hot-rolled steel sheet manufactured by the above-described manufacturing method may satisfy a yield strength of 350 MPa or more, a Charpy impact energy at -20°C of 27 J or more, and a vibration damping ratio of $100*10^{-6}$ or more. In this case, the vibration damping ratio refers to a vibration damping ratio measured at a frequency of 1650 Hz, after preparing a specimen with a length*width*thickness of 80mm*20mm*2mm in a flexural vibration mode.

[0095] The hot-rolled steel sheet manufactured by the above-described manufacturing method may satisfy an electrical resistivity of $35*10^{-8}$ Ωm or more, a yield ratio of 0.8 or less, and a yield ratio difference (ΔYR) in each direction of 10% or less. In this case, the yield ratio difference (ΔYR) for each direction may be defined as relational expression 6 below.

[Relational expression 6]

$$\Delta YR = (|YR_{RD} - YR_{TD}| * 100) / YR_{RD}$$

[0096] In the above Relational expression 6, YR_{RD} is a yield ratio in a direction, parallel to a rolling direction of the hot-rolled steel sheet, YR_{TD} is a yield ratio in a direction, perpendicular to the rolling direction of the hot-rolled steel sheet, and $|YR_{RD} - YR_{TD}|$ is an absolute value of a difference between the yield ratio (YR_{RD}) in a direction, parallel to the rolling direction and the yield ratio (YR_{TD}) in a direction, perpendicular to the rolling direction.

[0097] When the hot-rolled steel sheet manufactured by the above-mentioned manufacturing method is welded using submerged arc welding, a Charpy impact energy of the welded portion at -20°C may be 27 J or more, and a fraction of an M-A phase included in the welded portion may be 5 area% or less (including 0%). In this case, the welded portion may be a position 1 mm away from a fusion line.

[0098] Therefore, according to an aspect of the present disclosure, it is possible to provide a method for manufacturing a hot-rolled steel sheet having properties suitable for a vacuum train tube due to excellent yield strength, vibration damping ratio, and welded portion low-temperature toughness.

[0099] Hereinafter, a hot-rolled steel sheet for a vacuum train tube and a manufacturing method therefor of the present disclosure will be described in more detail through specific examples. The following embodiments may be for understanding the present disclosure, and may not be intended to specify the scope of the present disclosure. The scope of the present disclosure may be determined by matters described in the claims and matters reasonably inferred therefrom.

Mode for Invention

[0100] After preparing a steel slab having a thickness of 250 mm provided with an alloy composition shown in Table 1 below, a hot-rolled steel plate having a thickness of 15 mm was manufactured by applying process conditions in Table 2. Alloy components not listed in Table 1 below refer to impurities and a residual Fe, and the "-" sign indicates close to 0 wt% within an error range.

[Table 1]

Steel	Alloy Component (wt%)					
	C	Si	Mn	Ti	Nb	V
A	0.07	1.6	1.7	-	-	-

(continued)

Steel	Alloy Component (wt%)					
	C	Si	Mn	Ti	Nb	V
B	0.07	2.1	1.5	-	-	-
C	0.07	0.8	1.7	-	-	-
D	0.07	1	1.7	-	0.045	-
E	0.2	1	1.2	-	-	-
F	0.07	1.6	0.8	-	-	-
G	0.05	1.6	1.7	-	0.025	-

[Table 2]

Specimen No.	Steel	Process Condition			Relational expression 7
		Heating Temp. of Slab (T_1, °C),	Finish Rolling Temp. (T_2, °C)	Coiling Temp. (T_3, °C)	
1	A	1250	950	700	15
2	A	1250	880	600	5
3	A	1300	1000	750	22
4	B	1250	950	700	15
5	C	1250	950	700	15
6	D	1250	950	700	7
7	E	1250	950	700	7
8	F	1250	950	700	15
9	G	1250	950	700	12

[0101] Microstructures and mechanical properties of each specimen were analyzed and listed in Table 3, and whether Relational expressions 1 to 5 of each specimen were satisfied may be also listed in Table 3. The microstructures were measured using an optical microscope at 500x magnification after etching each specimen using a Nital etching method. A grain size of ferrite was measured according to ASTM E112. An aspect ratio of ferrite was measured using a length of the longest side of a grain and a length of a side, perpendicular thereto. FIG. 3 is an optical micrograph used to observe a microstructure of specimen 1. The mechanical properties were measured according to KS B 0802 and KS B 0810, and measured yield strength and yield ratio were listed in Table 4. When measuring the yield ratio, the yield ratio in a direction, parallel to a rolling direction of each specimen, and in a direction, perpendicular to the rolling direction, was measured, a yield ratio difference (ΔYR) for each direction, defined by relational expression 6, was calculated, and were described in Table 4 together.

[0102] A vibration damping ratio was measured at room temperature using IMCE's RFDA LTV800 after preparing a specimen with length*width*thickness of 80*20*2 mm. After hitting in a flexural vibration mode, the vibration damping ratio in a 1650 Hz region corresponding to a 1st mode among vibration modes of the specimen was measured and analyzed, and results therefrom were listed in Table 4. Electrical resistivity was measured according to KS C IEC 60404, and values thereof were listed in Table 4.

[0103] Submerged arc welding was performed on each specimen using a welding material containing C: 0.052 wt%, Mn: 1.53 wt%, Ni: 1.3 wt%, Mo: 0.135 wt%, a remaining Fe, and other inevitable impurities. During the submerged arc welding, a heat input of 20 kJ/cm^2 was applied to the inside, and a heat input of 22 kJ/cm^2 was applied to the outside. A -20°C Charpy impact toughness of the welded portion was measured according to KS B 0810, and results therefrom were listed in Table 4. For a region 1 mm away from a fusion line, first etching was performed using a solution of 5 g of EDTA and 0.5 g of NaF dissolved in 100 ml of distilled water, second etching was then performed using a solution of 25 g of NaOH and 5 g of picric acid dissolved in 100 ml of distilled water. The second etching was performed, and an M-A phase fraction was measured according to ASTM E 562.

[Table 3]

Specimen No.	Steel	Microstructure	Ferrite Average Particle Size (D_F, μm)	Ferrite Average Aspect Ratio (A_F)	Relational expression 1	Relational expression 2	Relational expression 3	Relational expression 4	Relational expression 5
1	A	F+P	15	1. 04	14.4	412	118	62	40.7
2	A	F+P	5	2.39	2.1	486	72	167	40.7
3	A	F+P	22	1.02	21.6	394	129	25	40.7
4	B	F+P	15	1.20	12.5	445	108	18	46.1
5	C	F+P	15	1.11	13.5	337	128	132	30.2
6	D	F+P	7	1. 98	3.5	403	97	187	32.8
7	E	F+P	7	2.06	3.4	426	74	159	30.6
8	F	F+P	15	1.05	14.3	350	105	62	35.5
9	G	F+P	13	1.22	10.7	411	116	82	40.6

[Table 4]

Specimen No.	Steel	Vibration Damping Ratio ($*10^{-6}$)	Yield Strength (MPa)	Roll Direction Yield Ratio	ΔYR (%)	Electical Resistivity ($*10^{-8}\Omega$m)	Welded Portion Charpy Energy (J, @-20°C)	Welded Portion M-A Phase Fraction (area%)
1	A	110	400	0.73	2.5	40.7	55	1
2	A	56	510	0.86	15.2	40.0	102	1
3	A	110	380	0.69	1.5	42.3	18	1
4	B	113	460	0.77	2.4	46.1	20	11
5	C	130	340	0.72	3	30.2	103	0
6	D	88	404	0.9	19	32.8	123	0
7	E	65	415	0.82	12.3	30.6	121	0
8	F	101	336	0.7	4.1	35.5	44	1
9	G	110	399	0.82	6.2	40.6	30	2

[0104] As shown in Tables 1 to 4, specimens that satisfy the alloy composition, process conditions, and Relational expressions 1 to 5 of the present disclosure satisfied a yield strength of 350 MPa or more, a vibration damping ratio of $100*10^{-6}$ or more, a yield ratio of 0.8 or less, a yield ratio difference (ΔYR) in each direction of 10% or less, and an electrical resistivity of 35*10-8Ωm or more, and a Charpy impact energy at -20°C of the welded portion satisfied 27 J or more. It can be seen that specimens not satisfying one or more of the conditions limited by the present disclosure did not simultaneously secure the desired properties.

[0105] In addition, for comparison with conventional materials, tests were conducted on EN-S355, an existing structural steel, under the same conditions. In EN-S355, it can be confirmed that a vibration damping ratio measured under the same conditions was only on a level of $60*10^{-6}$. FIG. 4 is an optical micrograph of EN-S355 taken using an optical microscope.

[0106] Therefore, according to an aspect of the present disclosure, it is possible to provide a hot-rolled steel sheet having excellent yield strength, yield ratio, vibration damping ratio, and low-temperature toughness, and low anisotropy of the yield ratio, and having properties suitable for a vacuum train tube, and a manufacturing method thereof.

[0107] Although the present disclosure has been described in detail through examples above, other forms of embodiments are also possible. Therefore, the technical spirit and scope of the claims set forth below are not limited to the embodiments.

Claims

1. A hot-rolled steel sheet for a vacuum train tube comprising, by weight, carbon (C): 0.03 to 0.11%, silicon (Si): 1.0 to 2.0%, manganese (Mn): 1.2 to 2.2%, a balance of Fe, and inevitable impurities,
wherein a microstructure comprises a composite structure in which pearlite is dispersed in a matrix structure of ferrite.

2. The hot-rolled steel sheet of claim 1, wherein an average particle size (D_F, pm) of the ferrite and an average aspect ratio (A_F) of the ferrite satisfy the following Relational expression 1:

[Relational expression 1]

$$7 \leq D_F/A_F \leq 20.$$

3. The hot-rolled steel sheet of claim 2, wherein the average particle size (D_F) of the ferrite satisfies a range of 8 to 20 μm.

4. The hot-rolled steel sheet of claim 2, wherein the average aspect ratio (A_F) of the ferrite is 2 or less.

5. The hot-rolled steel sheet of claim 1, wherein an amount of carbon (C) of the hot-rolled steel sheet is 0.05 to 0.09 wt%.

6. The hot-rolled steel sheet of claim 1, wherein an amount of silicon (Si) of the hot-rolled steel sheet is 1.4 to 1.8 wt%.

7. The hot-rolled steel sheet of claim 1, wherein an amount of manganese (Mn) of the hot-rolled steel sheet is 1.5 to 1.9 wt%.

8. The hot-rolled steel sheet of claim 1, wherein a total amount of titanium (Ti), niobium (Nb), and vanadium (V), inevitably included in the hot-rolled steel sheet, is less than 0.01% (including 0%).

9. The hot-rolled steel sheet of claim 1, wherein the hot-rolled steel sheet comprises one or more selected from chromium (Cr), nickel (Ni), copper (Cu), molybdenum (Mo), and tungsten (W), in a total amount of 1.0% or less (including 0%).

10. The hot-rolled steel sheet of claim 1, wherein the hot-rolled steel sheet satisfies any one or more of the following relational expressions 2 to 5 for the hot-rolled steel sheet:

[Relational expression 2]

$$355 \leq 11 + 394*D_F^{(-0.5)} + 448*[C] + 94*[Si] + 69*[Mn]$$

[Relational expression 3]

$$100 \leq 186 - 240*D_F^{(-0.5)} - 121*[C] - 13.2*[Si] + 13.7*[Mn]$$

[Relational expression 4]

$$27 \leq 476 - 95.22*\ln(D_F) - 220*[C] - 88*[Si]$$

[Relational expression 5]

$$35 \leq 9.5 + 5.2*[C] + 5.8*[Mn] + 13.1*[Si]$$

where D_F is an average particle size (pm) of ferrite included in the hot-rolled steel sheet, [C], [Si], and [Mn] are an amount of carbon (C), an amount of silicon (Si), and an amount of manganese (Mn), included in the hot-rolled steel sheet (wt%), and, when a component thereamong is not included, brackets including the component are substituted with zero (0) .

11. The hot-rolled steel sheet of claim 1, wherein the microstructure of the hot-rolled steel sheet comprises 60 to 90 area% of ferrite, 10 to 40 area% of pearlite, and an inevitable structure.

12. The hot-rolled steel sheet of claim 1, wherein yield strength of the hot-rolled steel sheet is 350 MPa or more, and a Charpy impact energy of the hot-rolled steel sheet at -20°C is 27 J or more.

13. The hot-rolled steel sheet of claim 1, wherein a vibration damping ratio measured at a frequency of 1650Hz in a flexural vibration mode, after processing the hot-rolled steel sheet into a specimen with a length*width*thickness of 80mm*20mm*2mm, is $100*10^{-6}$ or more.

14. The hot-rolled steel sheet of claim 1, wherein an electrical resistivity of the hot-rolled steel sheet is $35*10^{-8}\ \Omega m$ or more.

15. The hot-rolled steel sheet of claim 1, wherein a yield ratio in a direction, parallel to a rolling direction of the hot-rolled steel sheet, is 0.8 or less, and
a yield ratio difference (△YR) in each direction, defined by the following relational expression 6, is 10% or less:

[Relational expression 6]

$$\triangle YR = (|YR_{RD} - YR_{TD}| * 100) / YR_{RD}$$

where YR_{RD} is a yield ratio in a direction, parallel to a rolling direction of the hot-rolled steel sheet, YR_{TD} is a yield ratio in a direction, perpendicular to the rolling direction of the hot-rolled steel sheet, and $|YR_{RD} - YR_{TD}|$ is an absolute value of a difference between the yield ratio (YR_{RD}) in a direction, parallel to the rolling direction and the yield ratio (YR_{TD}) in a direction, perpendicular to the rolling direction.

16. The hot-rolled steel sheet of claim 1, wherein, in a welded portion formed by welding the hot-rolled steel sheet using submerged arc welding,

a Charpy impact energy of the welded portion at -20°C is 27 J or more, and
a fraction of an M-A phase included in the welded portion is 5 area% or less (including 0%).

17. The hot-rolled steel sheet of claim 1, wherein a thickness of the hot-rolled steel sheet is 10 mm or more.

18. A method for manufacturing a hot-rolled steel sheet for a vacuum train tube, comprising:

heating a slab to a heating temperature (T_1) of 1100°C to 1300°C, wherein the slab includes, by weight, carbon (C): 0.03 to 0.11%, silicon (Si): 1.0 to 2.0%, manganese (Mn): 1.2 to 2.2%, a balance of Fe, and inevitable impurities;
hot-rolling the heated slab at a finish rolling temperature (T_2) of 900°C to 1000°C to provide a hot-rolled steel sheet; and
coiling the hot-rolled steel sheet at a coiling temperature (T_3) of 600°C to 700°C,
wherein the finish rolling temperature (T_2) and the coiling temperature (T_3) satisfy the following Relational expression 7:

$$10 \leq -101.9 + 0.103*[T_2] + 0.0339*[T_3] - 61.9*[C] - 190.2*[Nb] \leq 20 \qquad \text{[Relational expression 7]}$$

where $[T_2]$ and $[T_3]$ are the finish rolling temperature (T_2, °C) and the coiling temperature (T_3, °C), [C] and [Nb] are an amount of carbon (C) and an amount of niobium (Nb), included in the hot-rolled steel sheet (wt%), and, when a component thereamong is not included, brackets including the component are substituted with zero (0).

19. The method of claim 18, wherein an amount of carbon (C) of the slab is 0.05 to 0.09 wt%.

20. The method of claim 18, wherein an amount of silicon (Si) of the slab is 1.4 to 1.8 wt%.

21. The method of claim 18, wherein an amount of manganese (Mn) of the slab is 1.5 to 1.9 wt%.

22. The method of claim 18, wherein a total amount of titanium (Ti), niobium (Nb), and vanadium (V), inevitably included in the slab, is less than 0.01% (including 0%).

23. The method of claim 18, wherein the slab comprises one or more selected from chromium (Cr), nickel (Ni), copper (Cu), molybdenum (Mo), and tungsten (W), in a total amount of 1.0% or less (including 0%).

24. The method of claim 18, wherein a thickness of the hot-rolled steel sheet is 10 mm or more.

FIG. 1

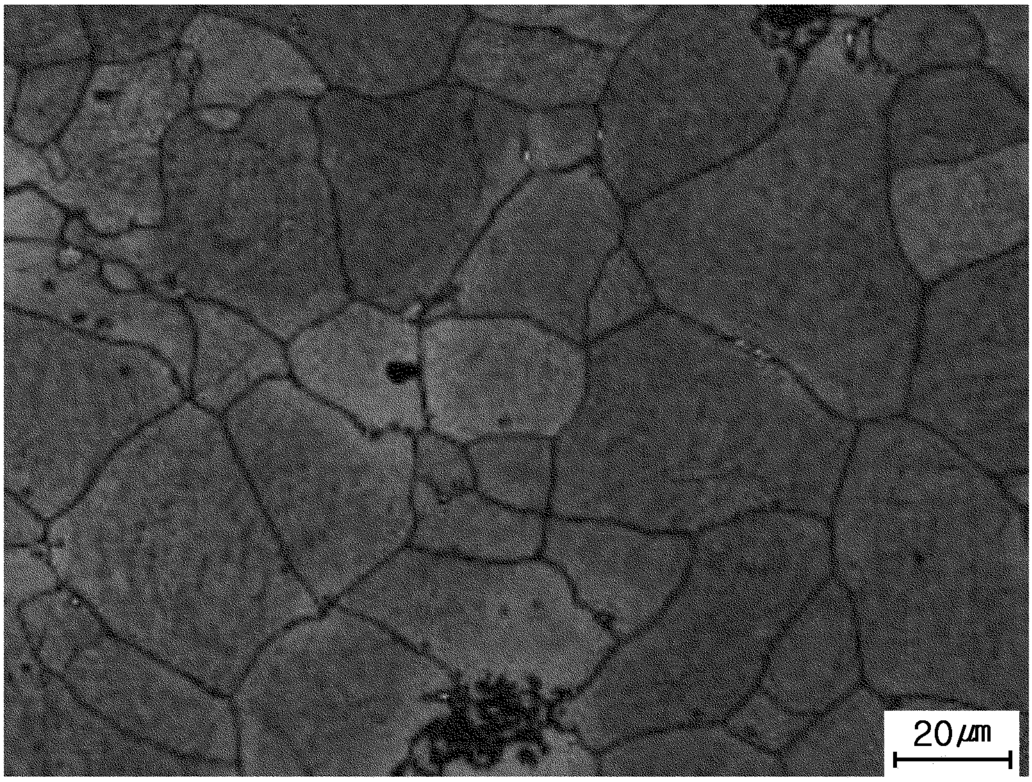


FIG. 2

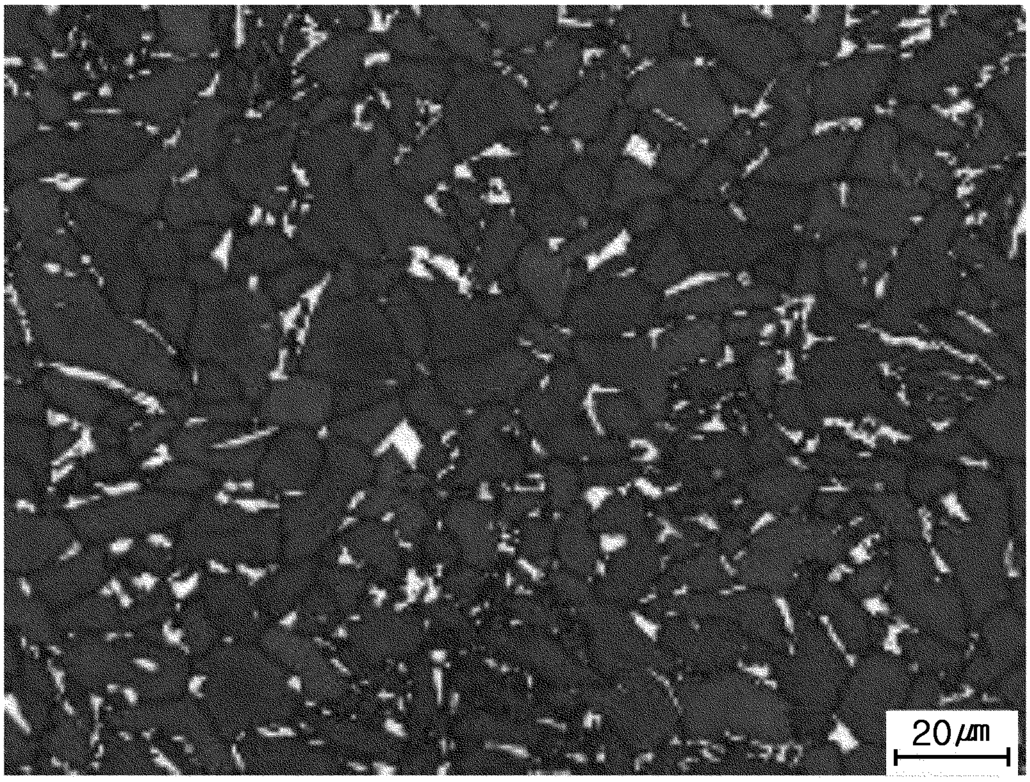


FIG. 3

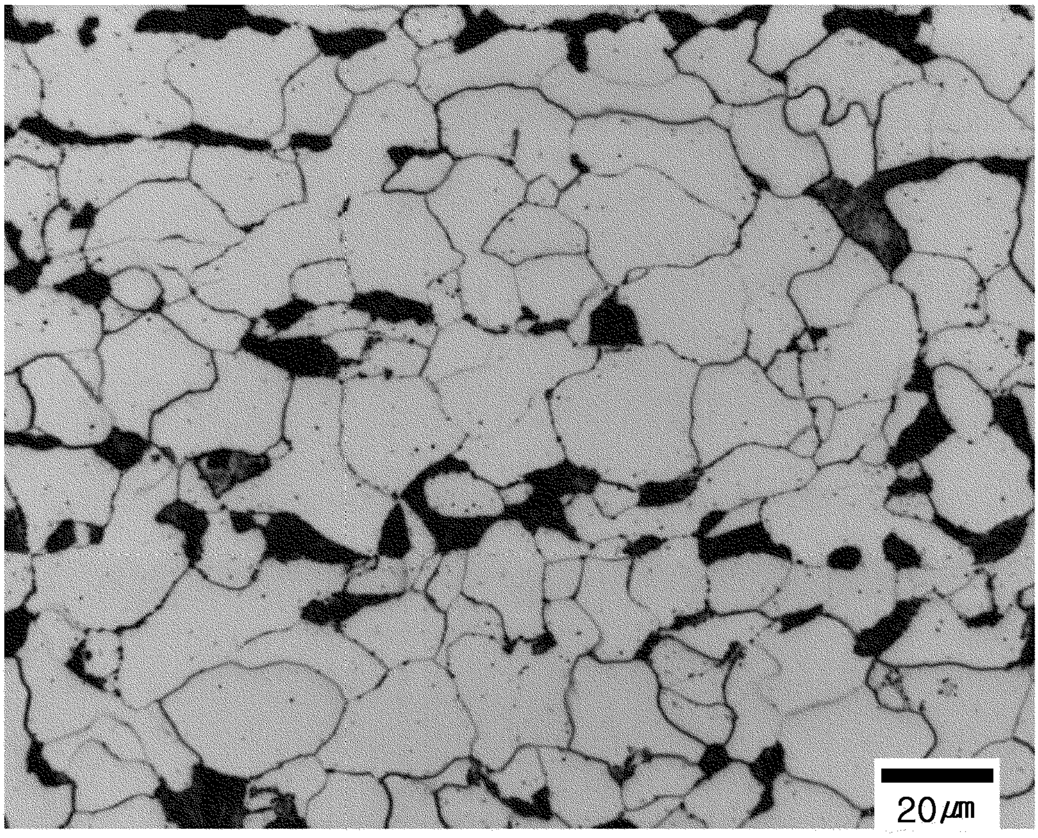
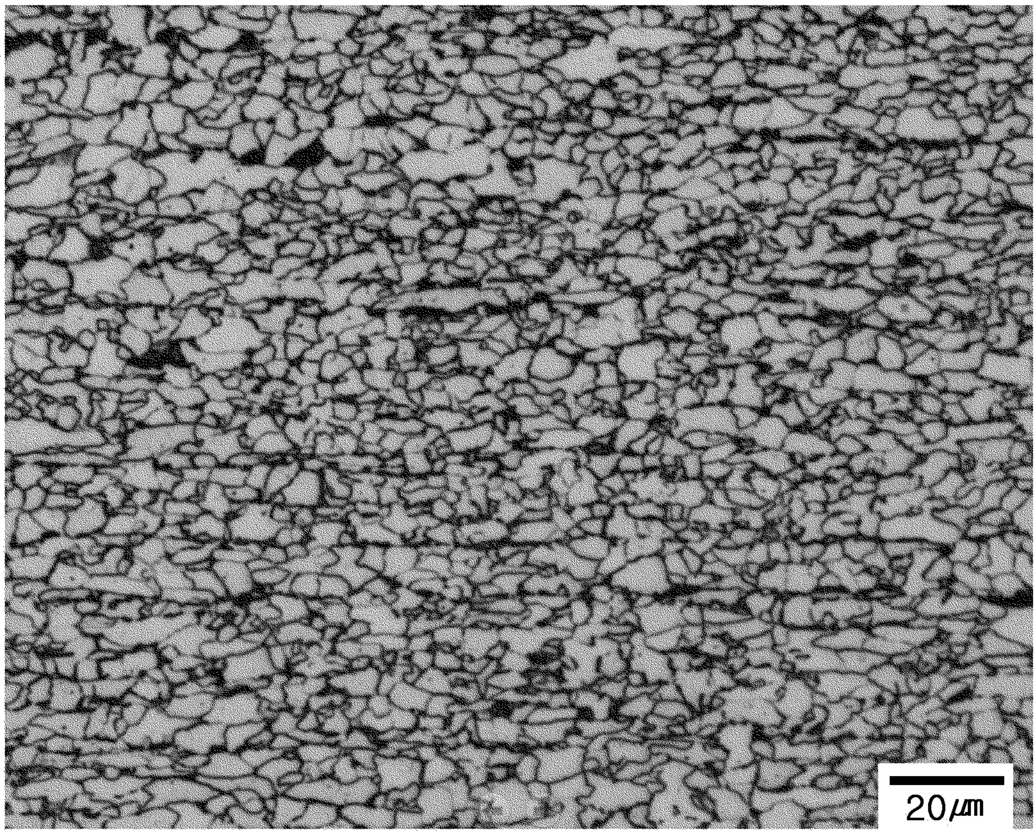


FIG. 4



INTERNATIONAL SEARCH REPORT

International application No. **PCT/KR2022/020722**

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/04(2006.01)i; **C22C 38/02**(2006.01)i; **C22C 38/14**(2006.01)i; **C22C 38/12**(2006.01)i; **C22C 38/38**(2006.01)i; **C22C 38/34**(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 38/04(2006.01); B21B 1/24(2006.01); C21D 8/02(2006.01); C22C 38/00(2006.01); C22C 38/06(2006.01); C22C 38/54(2006.01); C22C 38/58(2006.01); C22C 38/60(2006.01)

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

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

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

eKOMPASS (KIPO internal) & keywords: 열연강판(hot rolled steel), 진공 열차(hyper tube train), 페라이트(ferrite), 펄라이트(pearlite), 입자(grain), 실리콘(Si), 망간(Mn)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 10-2014-0044931 A (JFE STEEL CORPORATION) 15 April 2014 (2014-04-15) See paragraphs [0007], [0037], [0082] and [0110], claims 1, 3-4, 13 and 15 and table 4.	1-24
A	JP 2021-031701 A (NIPPON STEEL CORP.) 01 March 2021 (2021-03-01) See paragraph [0047] and claim 1.	1-24
A	JP 2007-291511 A (JFE STEEL K.K.) 08 November 2007 (2007-11-08) See paragraph [0035] and claims 1-2.	1-24
A	KR 10-2021-0078022 A (POSCO) 28 June 2021 (2021-06-28) See paragraph [0059] and claims 1-3.	1-24
A	WO 2012-002566 A1 (JFE STEEL CORPORATION) 05 January 2012 (2012-01-05) See claims 1 and 7.	1-24

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 March 2023	**24 March 2023**

Name and mailing address of the ISA/KR	Authorized officer
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2022/020722

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		EP 2752500 B1	26 October 2016
		JP 2013-049901 A	14 March 2013
		JP 5397437 B2	22 January 2014
		KR 10-1600725 B1	07 March 2016
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REFERENCES CITED IN THE DESCRIPTION

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- KR 102106353 **[0006]**