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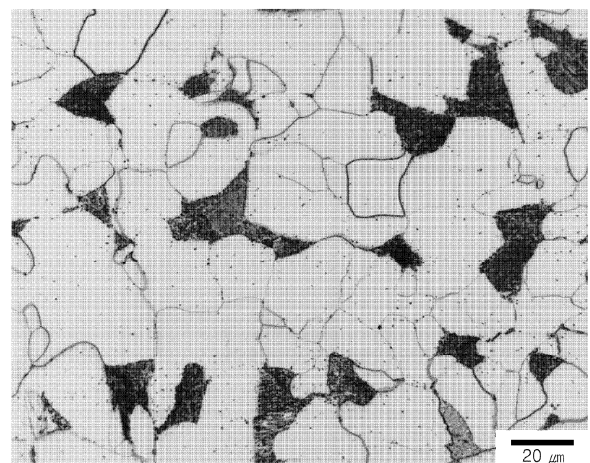
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(54) **HOT-ROLLED STEEL SHEET FOR VACUUM TRAIN TUBE**

(57) Disclosed is a hot-rolled steel sheet for a vacuum train tube, which is excellent in terms of yield strength, weldability, low-temperature toughness of a welded part, and a vibration damping ratio, while having no hot cracks. The hot-rolled steel sheet according to the present invention comprises, in weight%, C: 0.06% or less (more than 0%), Si: 0.5-1.5%, Mn: 1.2-2.2%, Cu: 0.5-1.5%, Ni: 0.25% or more, and Ti+Nb+V: 0.02% or less (including 0%), and the balance of Fe and inevitable impurities.

[FIG. 1]



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Description**[Technical Field]**

5 **[0001]** The present invention relates to a hot-rolled steel sheet for a vacuum train tube.

[Background Art]

10 **[0002]** A vacuum train, also known as a hyperloop, is a system in which a magnetically levitated train moves within a vacuum tube.

15 **[0003]** The vacuum train can operate at ultra-high speeds because there is no friction with air or tracks, which are major sources of energy loss during train operation. With minimal energy loss, the vacuum train can achieve up to 93% energy savings compared to aircraft, making it a promising eco-friendly, next-generation mode of transportation, and active research is underway worldwide.

20 **[0004]** The structures and materials of vacuum tubes used in ultra-high-speed vacuum trains affect the performance and cost of the system. Currently, three main materials are being studied as tube materials for a vacuum train. One is concrete. Concrete tubes are advantageous in terms of cost, but it is not easy to bond individual tubes of about 10 meters in length. In addition, pores within the concrete can easily allow external gases to penetrate the tube when a vacuum is created, easily breaking the vacuum. Another material that has been actively researched is composite materials, such as carbon fiber. Composite materials like carbon fiber are lightweight and high-performance, but their high cost is a major drawback.

25 **[0005]** Currently, the most promising material for a vacuum train tube is steel. Steel is a material that can be mass-produced at low cost. Steel is a material that has high rigidity and strength and is easily processed. In addition, steel is a material that facilitates the assembly and welding of components between tubes or to the tubes, and is also a material that has an appropriate outgassing rate when maintaining a vacuum. However, since ultra-high-speed vacuum trains operate at significantly higher speeds than current high-speed trains, the safety of passengers and surrounding facilities needs to be the top priority. Currently, safety standards for the ultra-high-speed vacuum trains have not been established, and the development of tube materials for a tube to ensure their safety is also inadequate.

30 **[0006]** Accordingly, there is an urgent need to develop materials for a vacuum train tube, which can have suitable processability and outgassing rates and secure safety.

[Disclosure]**[Technical Problem]**

35 **[0007]** The present invention is directed to providing a hot-rolled steel sheet for a vacuum train tube, which is excellent in terms of yield strength, weldability, low-temperature toughness of a welded part, and a vibration damping ratio and has no hot cracks.

40 **[0008]** Objects of the present invention are not limited to the above object, and other objects and advantages of the present invention which are not mentioned can be understood by the following description and more clearly understood by various embodiments of the present invention. In addition, it will be able to be easily seen that the objects and advantages of the present invention may be achieved by devices and combinations thereof that are described in the claims.

[Technical Solution]

45 **[0009]** A hot-rolled steel sheet according to the present invention contains 0.06 wt% or less (more than 0 wt%) of C, 0.5 to 1.5 wt% of Si, 1.2 to 2.2 wt% of Mn, 0.5 to 1.5 wt% of Cu, 0.25 wt% or more of Ni, 0.02 wt% or less (including 0 wt%) of Ti+Nb+V, and the balance of Fe and inevitable impurities in an alloy composition and contains greater than 90 area% of polygonal ferrite and less than 10 area% of pearlite based on the total area of 100%.

50 **[0010]** An average grain size of the polygonal ferrite may range from 8 to 20 μm .

55 **[0011]** The hot-rolled steel sheet may contain copper precipitates, wherein an ε -Cu precipitate fraction (%) according to ASTM E 562 may range from 0.3 to 1.5%.

60 **[0012]** In addition, it is preferable that no hot cracks occurs, and the hot cracks are defined as having a depth of 50 μm or more and a width of 5 μm or more.

65 **[0013]** In addition, a yield strength may be 350 MPa or more.

70 **[0014]** In addition, a Charpy impact energy at -20 °C may be 47 J/cm² or more.

75 **[0015]** After the hot-rolled steel sheet is processed into a specimen with a length*width*thickness of 80 mm*20

mm*2 mm, a vibration damping ratio measured at a frequency of 1650 Hz in a bending vibration mode may be 200×10^{-6} or more.

[0016] In a welded part formed by welding the hot-rolled steel sheet by means of submerged arc welding, a Charpy impact energy at -20 °C of the welded part may be 47 J/cm² or more, and a fraction of an M (martensite)-A (austenite) phase included in the welded part may be 5 area% or less (including 0 area%).

[0017] A hot-rolled steel sheet according to another embodiment of the present invention contains 0.06 wt% or less (more than 0 wt%) of C, 0.5 to 1.5 wt% of Si, 1.2 to 2.2 wt% of Mn, 0.5 to 1.5 wt% of Cu, 0.25 wt% or more of Ni, 0.02 wt% or less (including 0 wt%) of Ti+Nb+V, and the balance of Fe and inevitable impurities in an alloy composition.

[0018] A hot-rolled steel sheet according to still another embodiment of the present invention contains 0.06 wt% or less (more than 0 wt%) of C, 0.5 to 1.5 wt% of Si, 1.2 to 2.2 wt% of Mn, 0.5 to 1.5 wt% of Cu, 0.25 wt% or more of Ni, 0.02 wt% or less (including 0 wt%) of Ti+Nb+V, and the balance of Fe and inevitable impurities in an alloy composition and has an average grain size of polygonal ferrite of 8 to 20 μm.

[0019] A hot-rolled steel sheet according to yet another embodiment of the present invention contains 0.06 wt% or less (more than 0 wt%) of C, 0.5 to 1.5 wt% of Si, 1.2 to 2.2 wt% of Mn, 0.5 to 1.5 wt% of Cu, 0.25 wt% or more of Ni, 0.02 wt% or less (including 0 wt%) of Ti+Nb+V, and the balance of Fe and inevitable impurities in an alloy composition and has an ε-Cu precipitate fraction of 0.3 to 1.5% according to ASTM E 562.

[0020] A hot-rolled steel sheet according to yet another embodiment of the present invention contains 0.06 wt% or less (more than 0 wt%) of C, 0.5 to 1.5 wt% of Si, 1.2 to 2.2 wt% of Mn, 0.5 to 1.5 wt% of Cu, 0.25 wt% or more of Ni, 0.02 wt% or less (including 0 wt%) of Ti+Nb+V, and the balance of Fe and inevitable impurities in an alloy composition and has no hot cracks.

[0021] A hot-rolled steel sheet according to yet another embodiment of the present invention contains 0.06 wt% or less (more than 0 wt%) of C, 0.5 to 1.5 wt% of Si, 1.2 to 2.2 wt% of Mn, 0.5 to 1.5 wt% of Cu, 0.25 wt% or more of Ni, 0.02 wt% or less (including 0 wt%) of Ti+Nb+V, and the balance of Fe and inevitable impurities in an alloy composition and has a yield strength of 350 MPa or more.

[0022] A hot-rolled steel sheet according to yet another embodiment of the present invention contains 0.06 wt% or less (more than 0 wt%) of C, 0.5 to 1.5 wt% of Si, 1.2 to 2.2 wt% of Mn, 0.5 to 1.5 wt% of Cu, 0.25 wt% or more of Ni, 0.02 wt% or less (including 0 wt%) of Ti+Nb+V, and the balance of Fe and inevitable impurities in an alloy composition and has a Charpy impact energy of 47 J/cm² or more at -20 °C.

[0023] A hot-rolled steel sheet according to yet another embodiment of the present invention contains 0.06 wt% or less (more than 0 wt%) of C, 0.5 to 1.5 wt% of Si, 1.2 to 2.2 wt% of Mn, 0.5 to 1.5 wt% of Cu, 0.25 wt% or more of Ni, 0.02 wt% or less (including 0 wt%) of Ti+Nb+V, and the balance of Fe and inevitable impurities in an alloy composition and after the hot-rolled steel sheet is processed into a specimen with a length*width*thickness of 80 mm*20 mm*2 mm, has a vibration damping ratio of 200×10^{-6} or more measured at a frequency of 1650 Hz in a bending vibration mode.

[0024] A hot-rolled steel sheet according to yet another embodiment of the present invention contains 0.06 wt% or less (more than 0 wt%) of C, 0.5 to 1.5 wt% of Si, 1.2 to 2.2 wt% of Mn, 0.5 to 1.5 wt% of Cu, 0.25 wt% or more of Ni, 0.02 wt% or less (including 0 wt%) of Ti+Nb+V, and the balance of Fe and inevitable impurities in an alloy composition, wherein, in a welded part formed by welding the hot-rolled steel sheet by means of submerged arc welding, a Charpy impact energy is 47 J/cm² or more at -20 °C in the welded part and a fraction of an M (martensite)-A (austenite) phase included in the welded part is 5 area% or less (including 0 area%).

[Advantageous Effects]

[0025] The hot-rolled steel sheet for a vacuum train tube according to the present invention exhibits excellent yield strength, weldability, low-temperature toughness of the welded part, and vibration damping ratio and has no hot cracks during the manufacturing process.

[0026] In particular, in the hot-rolled steel sheet for a vacuum train tube according to the present invention, since the properties of the welded part can be easily secured, it is advantageous for forming into a tubular shape. In addition, its excellent elongation ensures structural stability even under internal and external pressure differences and stresses generated during train operation.

[0027] In addition, its excellent vibration damping ratio rapidly reduces vibrations generated during vacuum train operation. In addition, it is easy to manufacture because no cracks occur during hot working.

[0028] Specific effects together with the above effects are described together with a description of the following detailed matters for carrying out the invention.

[Description of Drawings]

[0029]

FIG. 1 is an optical microscope photograph of a microstructure of specimen 1 of the present invention.

FIG. 2 is an optical microscope photograph of EN-S355, which is a conventional structural steel.

[Mode for Invention]

[0030] The above-described objects, features, and advantages will be described below in detail with reference to the accompanying drawings, and thus those skilled in the art to which the present invention pertains will be able to easily carry out the technical spirit of the present invention. In describing the present invention, when it is determined that a detailed description of the known technology related to the present invention may unnecessarily obscure the gist of the present invention, a detailed description thereof will be omitted. Hereinafter, exemplary embodiments according to the present invention will be described in detail with reference to the accompanying drawings. In the drawings, the same reference numerals are used to denote the same or similar components.

[0031] Hereinafter, the arrangement of an arbitrary component on an "upper portion (or lower portion)" of a component or "above (or under)" the component may not only mean that the arbitrary component is disposed in contact with an upper surface (or a lower surface) of the component, but also mean that other components may be interposed between the component and the arbitrary component disposed above (or under) the component.

[0032] In addition, when a certain component is described as being "connected," "coupled," or "joined" to the other component, the components may be directly connected or joined, but it should be understood that another component may be "interposed" between the components, or the components may be "connected," "coupled," or "joined" through another component.

[0033] Hereinafter, a hot-rolled steel sheet for a vacuum train tube according to some embodiments of the present invention will be described.

[0034] A vacuum train, which runs inside a vacuum or sub-vacuum tube, is a next-generation transportation system currently in the early stages of development. By eliminating friction between wheels and tracks and minimizing air resistance, the vacuum train is a transportation system capable of effectively achieving high speeds and high efficiencies. However, due to the characteristics of vacuum trains operating at ultra-high speeds, there is a risk of major accidents when sufficient safety of the vacuum train is not ensured. In particular, since not only structural damage or collapse of the vacuum tube, but also deformation of a portion of the tube, can lead to major disasters, materials for a vacuum train tube require even stricter safety standards. Through in-depth research, the inventors have discovered that the following properties are crucial for ensuring the safety of vacuum trains.

[0035] The first property required for materials for a vacuum tube is high strength. Since the vacuum train passes through the inside of the vacuum tube, materials for a vacuum tube need to have sufficient structural strength. In addition, since the inside of a vacuum tube needs to be maintained in a vacuum or sub-vacuum state, it needs to have sufficiently high strength properties to prevent deformation of the tube's shape due to pressure differences between the inside and outside.

[0036] The second property required for materials for a vacuum tube is vibration damping. The vacuum train operates such that pods carrying several to several tens of passengers pass through the inside of a vacuum tube at intervals of several tens of seconds to several minutes. When a following pod passes through the vacuum tube after a preceding pod has passed therethrough, vibrations within the vacuum tube may be amplified, thereby inducing resonance, and in severe cases, causing damage or failure of the tube. Accordingly, when a material having a vibration damping ratio of a predetermined level or more is applied to the vacuum tube, vibrations within the tube after the preceding pod has passed therethrough can be effectively reduced, thereby contributing to the safety of the vacuum train.

[0037] A third property required for materials for a vacuum tube is low-temperature toughness. The vacuum trains may be operated in polar regions or deep-sea environments. Since steel materials tend to fracture more easily under low-temperature or cryogenic conditions, when steel is applied to vacuum tubes, it is required to have low-temperature toughness of a predetermined level or more to ensure safety. In particular, since tubes for a vacuum train are manufactured into tubular forms through welding, not only a base metal but also a welded part is required to exhibit excellent low-temperature toughness.

[0038] A fourth property required for materials for a vacuum tube is the absence of hot cracking during the manufacturing process.

[0039] Materials for mass production need to exhibit not only desirable final properties but also good manufacturability.

[0040] The present material is produced through continuous casting followed by hot rolling.

[0041] When steel containing Cu, as in the present invention, is heated to high temperatures during manufacturing, Fe, which has a higher ionization tendency than Cu, is selectively oxidized. When Fe oxidation causes the Cu solubility limit to be exceeded, it leads to the formation of liquid Cu. This liquid Cu penetrates along grain boundaries within the material, thereby inducing cracks. Cracks formed on a material surface may develop into more severe

defects during subsequent processing, and thus, it is important that the material be free of internal cracks, that is, hot cracking.

[0042] Through intensive research, the inventors of the present invention recognized that by strictly controlling the alloy composition and microstructure of the steel sheet, it is possible to simultaneously achieve excellent yield strength, vibration damping capacity, weldability, low-temperature toughness of the welded part, and the resistance to hot cracking, thereby leading to the present invention.

[0043] A hot-rolled steel sheet according to the present invention contains 0.06 wt% or less (more than 0 wt%) of C, 0.5 to 1.5 wt% of Si, 1.2 to 2.2 wt% of Mn, 0.5 to 1.5 wt% of Cu, 0.25 wt% or more of Ni, 0.02 wt% or less (including 0 wt%) of Ti+Nb+V, and the balance of Fe and inevitable impurities in an alloy composition and contains greater than 90 area% of polygonal ferrite and less than 10 area% of pearlite based on the total area of 100%.

[0044] Hereinafter, a steel composition included in a hot-rolled steel sheet according to one aspect of the present invention will be described in more detail. Hereinafter, unless otherwise stated, the percentages indicating the content of each element are based on weight.

Carbon (C): 0.06 wt% or less (greater than 0 wt%)

[0045] Carbon (C) is an element that significantly affects the vibration damping ratio of the steel sheet. As the carbon content increases, internal friction decreases, sharply reducing the vibration damping ratio. Accordingly, to achieve the objects of the present invention, the upper limit of the carbon content may be limited to 0.06 wt%.

[0046] Preferably, the hot-rolled steel sheet may contain 0.01 to 0.05 wt% of carbon (C).

Silicon (Si): 0.5 to 1.5 wt%

[0047] Silicon (Si) forms slag by oxygenation during a steelmaking operation, and thus tends to be removed together with oxygen. In addition, silicon (Si) is also an element that effectively contributes to improving the strength of the material. Accordingly, the present invention may contain 0.5 wt% or more of silicon (Si) to achieve these effects. On the other hand, an excessive silicon (Si) content may hinder the removal of surface scale, thereby degrading the product surface quality. In addition, the excessive silicon (Si) content may promote the formation of an M-A phase (martensite-austenite composite) in the welded part, thereby reducing the low-temperature toughness of the welded part, and thus the present invention may limit the silicon (Si) content to 1.5 wt% or less.

[0048] Preferably, the hot-rolled steel sheet may contain 0.6 to 1.0 wt% of silicon (Si).

Manganese (Mn): 1.2 to 2.2 wt%

[0049] Manganese (Mn) is an element that improves the strength and hardenability of steel. Accordingly, the present invention may contain 1.2 wt% or more of manganese (Mn) to achieve these effects. On the other hand, an excessive manganese (Mn) content can cause material deviation due to center segregation and deteriorate crack propagation resistance. In addition, since the excessive manganese (Mn) content can degrade the toughness of the steel, the present invention may limit the manganese (Mn) content to 2.2 wt% or less.

[0050] Preferably, the hot-rolled steel sheet may contain 1.4 to 2.0 wt% of manganese (Mn).

Copper (Cu): 0.5 to 1.5 wt%

[0051] Copper (Cu) is an element that precipitates in steel and enhances its strength. Accordingly, the present invention may contain 0.5 wt% or more of Cu to achieve these effects. Cu causes segregation during manufacturing, and the Cu-enriched region lowers the melting point, forming a liquid film during casting and degrading high-temperature ductility. This reduced ductility can cause cracks in the material during manufacturing.

[0052] Accordingly, the copper (Cu) content may be limited to 1.5 wt% or less.

[0053] Preferably, the hot-rolled steel sheet may contain 0.6 to 1.2 wt% of copper (Cu).

Nickel (Ni): 0.25 wt% or more

[0054] Nickel (Ni) is an element that prevents the reduction in high-temperature ductility caused by copper (Cu). In addition, nickel (Ni) also helps improve the toughness of the steel. To prevent the reduction in high-temperature ductility, a minimum of 0.5 times the copper content is required.

[0055] From this perspective, the nickel (Ni) content of 0.25 wt% or more may be contained, and up to 3.0 wt% of nickel (Ni) is preferably contained in consideration of the increased cost.

[0056] Titanium (Ti), niobium (Nb), vanadium (V): A total of 0.02 wt% (including 0 wt%)

[0057] Titanium (Ti), niobium (Nb), and vanadium (V) are elements that refine grain size by delaying recrystallization of steel during rolling. However, since a reduction in grain size deteriorates the vibration damping ratio, the total addition amount of these elements is limited to 0.02 wt% or less in the present invention.

[0058] Preferably, the combined content of titanium (Ti), niobium (Nb), and vanadium (V) may be 0 wt%.

[0059] The hot-rolled steel sheet of the present invention may contain the balance of Fe and other inevitable impurities in addition to the above components. However, in a conventional manufacturing process, unintended impurities may inevitably be introduced from raw materials or the surrounding environment, and thus may not be completely excluded. Since these impurities are readily apparent to those skilled in the art, not all of them are specifically described herein. In addition, the addition of additional effective components other than the above components is not completely excluded.

[0060] The hot-rolled steel sheet of the present invention may contain polygonal ferrite and pearlite as its microstructure. Low-temperature structures such as bainite and martensite are excluded due to concerns about deteriorating toughness.

[0061] Since the hot-rolled steel sheet for a vacuum train tube of the present invention is thick, typically at least 10 mm, low-temperature structures are formed only on the surface of the steel sheet, and it is difficult for the low-temperature structures to fully extend to the center of the steel sheet.

[0062] Accordingly, to suppress property differences in a thickness direction of the steel sheet, the present invention provides a microstructure composed of a polygonal ferrite matrix in which pearlite is dispersed, and even when low-temperature structures such as bainite and martensite are inevitably formed, their fraction can be actively suppressed to 1 area% or less (including 0 area%).

[0063] Here, the term "matrix" refers to a structure occupying a fraction of 50 area% or more when the microstructure of the hot-rolled steel sheet is observed.

[0064] The ferrite structure of the present invention is polygonal ferrite (PF), and the polygonal ferrite refers to a completely polygonal (polygonal) ferrite as a structure that is formed by phase transformation of austenite deformed at high temperatures in a temperature range of 700 °C or higher.

[0065] In terms of securing properties, the microstructure may contain more than 90 area% of polygonal ferrite and less than 10 area% of pearlite based on the total area of 100% and preferably contain 92 to 100 area% of polygonal ferrite.

[0066] To simultaneously achieve the desired excellent yield strength, vibration damping ratio, low-temperature toughness, and resistance to hot cracking, the present invention may limit the average grain size of the polygonal ferrite grains to a predetermined range. While a smaller average grain size of the polygonal ferrite grains improves strength and toughness, the vibration damping ratio may deteriorate, and thus the present invention increases the average grain size of the polygonal ferrite grains, thereby securing the vibration damping ratio, and uses Cu precipitates formed under conditions in which the average grain size of the polygonal ferrite grains is controlled, thereby securing yield strength and low-temperature impact toughness.

[0067] Since a larger average grain size of polygonal ferrite is advantageous for securing a vibration damping ratio, the average grain size of the polygonal ferrite grains may range from 8 to 20 μm , preferably from 10 to 18 μm .

[0068] When the average grain size of the polygonal ferrite grains exceeds 20 μm , the strength and low-temperature toughness of the material deteriorate, and thus the average grain size of the polygonal ferrite grains may be limited to 20 μm or less.

[0069] The Cu precipitates preferably includes a Cu-only precipitate called epsilon (ϵ)-Cu. The ϵ -Cu precipitate fraction (%) may range from 0.3 to 1.5%, preferably from 0.3 to 1.3%. By forming Cu precipitates under conditions in which the average grain size of the polygonal ferrite grains is controlled, yield strength and low-temperature impact toughness can be improved.

[0070] When the ϵ -Cu precipitate fraction (%) is less than 0.3%, the yield strength may decrease. Conversely, when the ϵ -Cu precipitate fraction (%) exceeds 1.5%, hot cracks may occur during the manufacturing process as the ϵ -Cu precipitate fraction increases.

[0071] The hot-rolled steel sheet for a vacuum train tube of the present invention may exhibit a yield strength of at least 350 MPa, preferably 356 to 500 MPa.

[0072] In addition, the hot-rolled steel sheet for a vacuum train tube may exhibit a Charpy impact energy of at least 47 J/cm² at -20 °C, preferably 50 to 300 J/cm², and more preferably 50 to 208 J/cm².

[0073] In this way, the hot-rolled steel sheet for a vacuum train tube of the present invention can secure excellent strength and low-temperature toughness as a structural material, thereby effectively ensuring the structural safety of the vacuum train tube.

[0074] When the hot-rolled steel sheet is processed into a specimen with a length*width*thickness of 80mm*20mm*2mm and then subjected to a flexural vibration mode, the vibration damping ratio measured for a frequency of 1650 Hz may be 200×10^{-6} or more, preferably 200×10^{-6} to 400×10^{-6} , and more preferably 200×10^{-6} to 350×10^{-6} .

[0075] The hot-rolled steel sheet for a vacuum train tube of the present invention exhibits a vibration damping ratio of 200×10^{-6} or more, thereby effectively suppressing vibration amplification within the vacuum tube and effectively preventing damage to the vacuum train tube due to vibration.

[0076] In a welded part formed by welding the hot-rolled steel sheet using submerged arc welding, the Charpy impact energy of the weld may be 47 J/cm² or more at -20 °C, and the fraction of the M (martensite)-A (austenite) phase in the welded part may be 5 area% or less (including 0 area%) based on the total area of 100 area%. The preferred MA phase fraction in the welded part may be 3 area% or less, and a more preferred M-A phase fraction in the welded part may be 2 area% or less.

[0077] Generally, the welded part is composed of a hard phase, such as martensite, and the grain size is also large. The microstructure of the hard phase may serve as an impact notch site when evaluating Charpy impact energy, thereby reducing the ductile fracture rate, and as the average grain size of the hard phase increases, the impact toughness of the weld deteriorates compared to the base metal.

[0078] However, in the present invention, the fraction of the M (martensite)-A (austenite) phase in the microstructure of the welded part was minimized to 5 area% or less, thereby securing low-temperature toughness even in the welded part. A 95 area% or more of the microstructure in the welded part varies depending on the location, acicular ferrite and granular bainitic ferrite are formed closer to the molten metal, and polygonal ferrite and pearlite similar to the base metal begin to appear toward the base metal.

[0079] The acicular ferrite is a structure formed during the cooling or coiling process, and its internal structure is composed of laths, such as wooden sticks. Accordingly, this structure achieves a grain size refinement effect, resulting in an excellent combination of strength and ductility. The acicular ferrite is also referred to as acicular ferrite or needle-like acicular ferrite.

[0080] The granular bainitic ferrite is a structure formed during continuous cooling and composed of irregularly shaped bainitic ferrite and carbon-enriched secondary phases, such as martensite-austenite (MA) and exhibits a high internal dislocation density.

[0081] Here, the welded part may be interpreted as a region located 1 mm from a fusion line and including both a weld metal and a heat-affected zone (HAZ).

[0082] The submerged arc welding is a welding method that includes inserting a bare electrode wire into a finely granular flux deposited on the surface of the joint and welding with the arc heat generated between the wire and the base metal. During submerged arc welding, a heat input of 20 kJ/cm² is applied to the inside, and a heat input of 22 kJ/cm² may be applied to the outside.

[0083] Although the welding material used for welding in the present invention is not particularly limited, it is preferable to perform welding using a welding material that does not contain silicon (Si), if possible. This is because, when welding using a welding material containing silicon (Si), excessive hardenability can lead to the formation of a large amount of hardened M-A gaps at the welded part.

[0084] The hot-rolled steel sheet of the present invention may exhibit excellent yield strength, vibration damping ratio, and low-temperature toughness and at the same time, may exhibit no hot cracks during the manufacturing process, making it advantageous for use as a material for a vacuum train tube.

[0085] There is no hot cracks during the manufacturing process, and the hot-rolled steel sheet produced remains free of hot cracks.

[0086] Here, the term "hot cracks" refers to cracks that occur on the surface of a slab after casting or reheating, or cracks on the surface of a steel sheet after hot rolling. Cracks may be defined as having a depth of 50 μm or more and a width of 5 μm or more.

[0087] A method of manufacturing a hot-rolled steel sheet for a vacuum train tube according to the present invention includes heating a slab containing 0.06 wt% or less (more than 0 wt%) of C, 0.5 to 1.5 wt% of Si, 1.2 to 2.2 wt% of Mn, 0.5 to 1.5 wt% of Cu, 0.25 wt% or more of Ni, 0.02 wt% or less (including 0 wt%) of Ti+Nb+V, and the balance of Fe and inevitable impurities at a heating temperature of 1100 to 1300 °C, providing a hot-rolled steel sheet by hot-rolling the heated slab at a finishing rolling temperature of 860 to 960 °C, and coiling the hot-rolled steel sheet at a coiling temperature of 600 to 700 °C.

[0088] A steel slab having the above alloy composition is prepared. Since the steel slab of the present invention has an alloy composition corresponding to that of the above hot-rolled steel sheet, the description of the alloy composition of the steel slab will be replaced with the description of the alloy composition of the above hot-rolled steel sheet.

[0089] The prepared steel slab may be heated at a heating temperature of 1100 to 1300 °C. Considering a rolling load during hot rolling, the steel slab may be heated within a temperature range of 1100 °C or higher. In particular, since the present invention seeks to introduce a microstructure of a predetermined size or larger, the preferred heating temperature of the steel slab may be 1200 °C or higher, and a more preferred heating temperature may be 1250 °C or higher.

[0090] On the other hand, excessively high heating temperatures can lead to deterioration of surface quality due to scale formation, and thus, the present invention limits the heating temperature of the steel slab to 1300 °C or lower.

[0091] A heated steel slab may be hot-rolled at a finishing rolling temperature of 860 to 960 °C to produce a hot-rolled steel sheet. The steel sheet produced by the hot rolling process of the present invention may have a thickness of 10 mm or more. During hot rolling, the grains are deformed as the material is rolled, but are soon recrystallized. Through this process, coarse and uneven grains become refined and homogenized. A key process variable during hot rolling is a finishing delivery temperature (FDT). This is because the final microstructure fraction, grain size, etc. may be controlled by the FDT. Here, the term "FDT" refers to the temperature at the completion of rolling and denotes the measured value of the steel sheet surface at the exit side of the finishing mill.

[0092] Since the present invention seeks to control the final microstructure to a predetermined size or higher, hot rolling may be performed at a FDT of 860 °C or higher. The preferred FDT may be 900 °C or higher. On the other hand, when the FDT is excessively high, the final microstructure may be excessively coarse, and thus, the present invention may limit the upper limit of the FDT to 960 °C.

[0093] The hot-rolled steel sheet produced by hot rolling may be coiled at a coiling temperature (CT) of 600 to 700 °C after water cooling. Since the present invention seeks to achieve polygonal ferrite and pearlite structures as a final structure, coiling may be performed within a temperature range of 600 °C or higher. Since the present invention seeks to achieve a final microstructure of a predetermined size or more, coiling is preferably performed within a temperature range of 630 °C or higher. However, when the coiling temperature is excessively high, coarse microstructures may be formed or surface quality may be degraded, and thus, the present invention may limit the upper limit of the coiling temperature to 700 °C.

[0094] The cooling rates in the water-cooling and coiling operations may be performed at conventional cooling rates.

[0095] Accordingly, the method of manufacturing a hot-rolled steel sheet for a vacuum train tube according to the present invention includes heating a slab at a heating temperature of 1100 to 1300 °C, hot rolling at a finishing rolling temperature of 860 to 960 °C, and coiling the hot-rolled steel sheet at a coiling temperature of 600 to 700 °C.

[0096] In this way, specific examples of the hot-rolled steel sheet for a vacuum train tube will be described as follows.

1. Manufacture of hot-rolled steel sheets

[0097] 250 mm-thick steel slabs having alloy compositions shown in Table 1 below were prepared, and 15 mm-thick hot-rolled steel sheets were manufactured using process conditions shown in Table 2.

[0098] Alloy components not listed in Table 1 below represent the balance of impurities and Fe.

[0099] In Table 2, a FDT denotes a finishing rolling temperature, and a CT denotes a coiling temperature.

[Table 1]

Alloy (wt%)	C	Si	Mn	Cu	Ni	Nb+Ti+V
A	0.03	1.0	1.8	1.0	0.5	0
A-1	0.03	1.0	1.8	1.0	0.5	0.015
A-2	0.06	1	1.8	1	0.5	0
A-3	0.03	0.5	1.8	1	0.5	0
A-4	0.03	1.5	1.8	1	0.5	0
A-5	0.03	1	1.2	1	0.5	0
A-6	0.03	1	2.2	1	0.5	0
A-7	0.03	1	1.8	0.5	0.5	0
A-8	0.03	1	1.8	1.5	0.5	0
A-9	0.03	1	1.8	1	0.25	0
B	0.09	1.0	1.8	1.0	0.5	0
C	0.03	0.4	1.8	1.0	0.5	0
D	0.03	2.0	1.8	1.0	0.5	0
E	0.03	1.0	1.0	1.0	0.5	0
F	0.03	1.0	2.5	1.0	0.5	0
G	0.03	1.0	1.8	0.4	0.2	0
H	0.03	1.0	1.8	2.0	2.0	0

(continued)

Alloy (wt%)	C	Si	Mn	Cu	Ni	Nb+Ti+V
I	0.03	1.0	1.8	1.0	0.5	0.05

2. Physical property evaluation method and its results

[0100]

1) The microstructure and mechanical properties of each specimen were analyzed and are shown in Tables 2 and 3.

[0101] The average grain size of polygonal ferrite was measured according to ASTM E112, and the polygonal ferrite fraction was measured using an image analyzer according to ASTM E 562.

[0102] The material microstructure of the base metal was measured using an optical microscope at 500x magnification after etching each specimen using the Nital etching method.

[0103] The ϵ -Cu precipitate fraction (%) was measured using SEM images at 10,000x magnification according to ASTM E 562.

[0104] 2) The specimens were subjected to the submerged arc welding using the welding material containing C: 0.052 wt%, Mn: 1.53 wt%, Ni: 1.3 wt%, Mo: 0.135 wt%, and the balance of Fe and other inevitable impurities. During submerged arc welding, a heat input of 20 kJ/cm² was applied to the inside, and a heat input of 22 kJ/cm² was applied to the outside. Charpy impact energy of the welded part was measured at -20 °C according to KS B 0810, and the results are shown in Table 3.

[0105] For a region located 1 mm from the fusion line, primary etching was performed using a solution prepared by dissolving 5 g of EDTA and 0.5 g of NaF in 100 ml of distilled water, followed by secondary etching using a solution prepared by dissolving 25 g of NaOH and 5 g of picric acid in 100 ml of distilled water, and the fraction of the MA phase in the welded part was measured according to ASTM E 562.

[0106] 3) Mechanical properties were measured according to KS B 0802 and KS B 0810, and the measured yield strengths are shown in Table 3.

[0107] 4) The vibration damping ratio was measured at room temperature using IMCE's RFDA LTV800 on specimens having 80*20*2 mm in length*width*thickness.

[0108] After impact excitation in a bending vibration mode, the vibration damping ratio in the 1650 Hz region corresponding to a first mode of the specimen was measured and analyzed, and the results are shown in Table 3.

[0109] 5) Hot crack measurement method and definition of crack: After hot rolling during the manufacturing process according to Table 2, the presence of cracks on the steel sheet surface was visually checked, and hot cracks are defined as those with a depth of 50 μ m or more and a width of 5 μ m or more.

[Table 2]

Specimen No.	Steel grade	FDT (°C)	CT (°C)	Average grain size (μ m)	Polygonal ferrite fraction (area%)	ϵ -Cu precipitate fraction (%)	M-A phase fraction in welded part (area%)
1	A	910	670	17.0	97	0.8	1
1-1	A-1	910	670	15.0	98	0.7	1
1-2	A-2	910	670	10	92	0.6	1
1-3	A-3	910	670	15	96	0.7	1
1-4	A-4	910	670	18	98	0.8	2
1-5	A-5	910	670	18	95	1	1
1-6	A-6	910	670	13	98	0.6	2
1-7	A-7	910	670	16	94	0.3	1
1-8	A-8	910	670	14	95	1.3	2
1-9	A-9	910	670	17	93	0.6	1

(continued)

Specimen No.	Steel grade	FDT (°C)	CT (°C)	Average grain size (μm)	Polygonal ferrite fraction (area%)	ε-Cu precipitate fraction (%)	M-A phase fraction in welded part (area%)
2	B	910	670	9.0	89	0.8	2
3	C	910	670	8.5	97	0.8	1
4	D	910	670	9.2	95	0.8	8
5	E	910	670	14.3	95	0.9	1
6	F	910	670	11.0	98	0.8	2
7	G	910	670	13.7	97	0.4	1
8	H	910	670	11.8	96	1.9	1
9	I	910	670	14.4	94	0.7	1
10	A	980	720	21.0	95	0.8	1
11	A	850	590	7.8	94	0.9	1

[Table 3]

Specimen No.	Steel grade	Yield strength (MPa)	Charpy impact energy (J/cm ²)	Vibration damping ratio (10 ⁻⁶)	Hot cracks
1	A	370	102	270	None
1-1	A-1	406	88	205	None
1-2	A-2	408	62	202	None
1-3	A-3	360	208	266	None
1-4	A-4	410	51	302	None
1-5	A-5	361	108	322	None
1-6	A-6	410	111	211	None
1-7	A-7	356	172	244	None
1-8	A-8	422	50	230	None
1-9	A-9	371	99	260	None
2	B	420	66	160	None
3	C	330	150	210	None
4	D	411	11	206	None
5	E	344	110	244	None
6	F	416	102	152	None
7	G	290	144	255	None
8	H	440	177	270	Occurrence
9	I	420	150	140	None
10	A	290	3	350	None
11	A	420	170	111	None

[0110] As shown in Tables 1 to 3, specimen 1 satisfied both the alloy composition and process conditions of the present invention and exhibited excellent yield strength, vibration damping capacity, low-temperature toughness, and resistance to of hot cracking.

[0111] FIG. 1 is an optical micrograph used for observing the microstructure of specimen 1.

[0112] Referring to FIG. 1, the microstructure is composed of about 97 area% of polygonal ferrite appearing white and about 3 area% of pearlite appearing black.

[0113] Specimens 1-1 to 1-9, in which Ti+Nb+V was 0.02 wt% or less and all process conditions were satisfied, exhibited, as in specimen 1, excellent yield strength, vibration damping capacity, low-temperature toughness, and resistance to hot cracking.

[0114] Specimen 2 had a carbon (C) content exceeding 0.06 wt%, resulting in a polygonal ferrite fraction of 90% or less and a vibration damping ratio of less than 200×10^{-6} .

[0115] Specimen 3 had a silicon (Si) content of less than 0.5 wt%, resulting in a yield strength of less than 350 MPa.

[0116] Specimen 4 had a silicon (Si) content exceeding 1.5 wt%, and the fraction of the M (martensite)-A (austenite) phase in the welded part exceeded 5 area%, and the low-temperature impact toughness was less than 47 J/cm².

[0117] Specimen 5 had a manganese (Mn) content of less than 1.2 wt%, resulting in a yield strength of less than 350 MPa.

[0118] Specimen 6 had a manganese (Mn) content exceeding 2.2 wt%, resulting in a vibration damping ratio of less than 200×10^{-6} .

[0119] Specimen 7 had a copper (Cu) content of less than 0.5 wt% and a nickel (Ni) content of less than 0.25 wt%, resulting in an ϵ -Cu precipitate fraction exceeding 0.3% and a yield strength of less than 350 MPa.

[0120] Specimen 8 had a copper (Cu) content exceeding 1.5 wt%, resulting in an ϵ -Cu precipitate fraction exceeding 1.5%, which led to the occurrence of hot cracks.

[0121] When the Cu content exceeds 1.5 wt%, Fe, which has a higher ionization tendency than Cu, is selectively oxidized during high-temperature heating in the manufacturing process. When Fe oxidation causes the Cu solubility limit to be exceeded, liquid Cu forms, penetrates along grain boundaries within the material, and induces cracking, thereby resulting in the occurrence of hot cracks.

[0122] Specimen 9 had a combined Ti+Nb+V content exceeding 0.02 wt%, resulting in a vibration damping ratio of less than 200×10^{-6} .

[0123] Specimen 10 exceeded the FDT and the coiling temperature and had an average polygonal ferrite grain size exceeding 20 μ m, and although vibration damping capacity was secured due to the excessively large grain size, the yield strength was less than 350 MPa and the low-temperature impact toughness was less than 47 J/cm².

[0124] Specimen 11 was less than the FDT and the coiling temperature and had an average polygonal ferrite grain size of less than 8 μ m, and as the grain size became excessively small, the vibration damping ratio was less than 200×10^{-6} .

[0125] Accordingly, it can be seen that specimens satisfying not only the alloy composition and process conditions of the present invention exhibited a yield strength of 350 MPa or more and a vibration damping ratio of 200×10^{-6} or more, but also a Charpy impact energy of 47 J/cm² or more at -20 °C in the welded part and had no hot cracks, but specimens that failed to satisfy at least one of the conditions defined in the present invention could not simultaneously achieve the desired properties.

[0126] FIG. 2 is an optical micrograph of EN-S355 taken using an optical microscope.

[0127] For comparison with conventional materials, tests were conducted under the same conditions using EN-S355 (0.15 wt% of C+1.2 wt% of Mn+0.025 wt% of Nb), which is a conventional structural steel, and in the case of EN-S355, the vibration damping ratio measured under the same conditions was only about 60×10^{-6} .

[0128] Accordingly, according to the present invention, a hot-rolled steel sheet for a vacuum train tube having excellent yield strength, vibration damping capacity, low-temperature toughness in a welded part, and resistance to hot cracking can be provided.

[0129] Although the present invention has been described above with reference to the exemplary drawings, the present invention is not limited by the embodiments and drawings disclosed in the specification, and it is apparent that various modifications can be made by those skilled in the art within the scope of the technical spirit of the present invention. In addition, even when the operational effects according to the configuration of the present invention have not been explicitly described in the description of the embodiments of the present invention, it goes without saying that the effects predictable by the corresponding configuration should be recognized.

Claims

1. A hot-rolled steel sheet comprising: 0.06 wt% or less (more than 0 wt%) of C, 0.5 to 1.5 wt% of Si, 1.2 to 2.2 wt% of Mn, 0.5 to 1.5 wt% of Cu, 0.25 wt% or more of Ni, 0.02 wt% or less (including 0 wt%) of Ti+Nb+V, and the balance of Fe and inevitable impurities in an alloy composition; and greater than 90 area% of polygonal ferrite and less than 10 area% of pearlite based on the total area of 100%.

2. The hot-rolled steel sheet of claim 1, wherein an average grain size of the polygonal ferrite ranges from 8 to 20

μm.

3. The hot-rolled steel sheet of claim 1, comprising copper precipitates, wherein an ε-Cu precipitate fraction (%) according to ASTM E 562 ranges from 0.3 to 1.5%.

4. The hot-rolled steel sheet of claim 1, which has no hot cracks
(the hot cracks are defined as having a depth of 50 μm or more and a width of 5 μm or more).

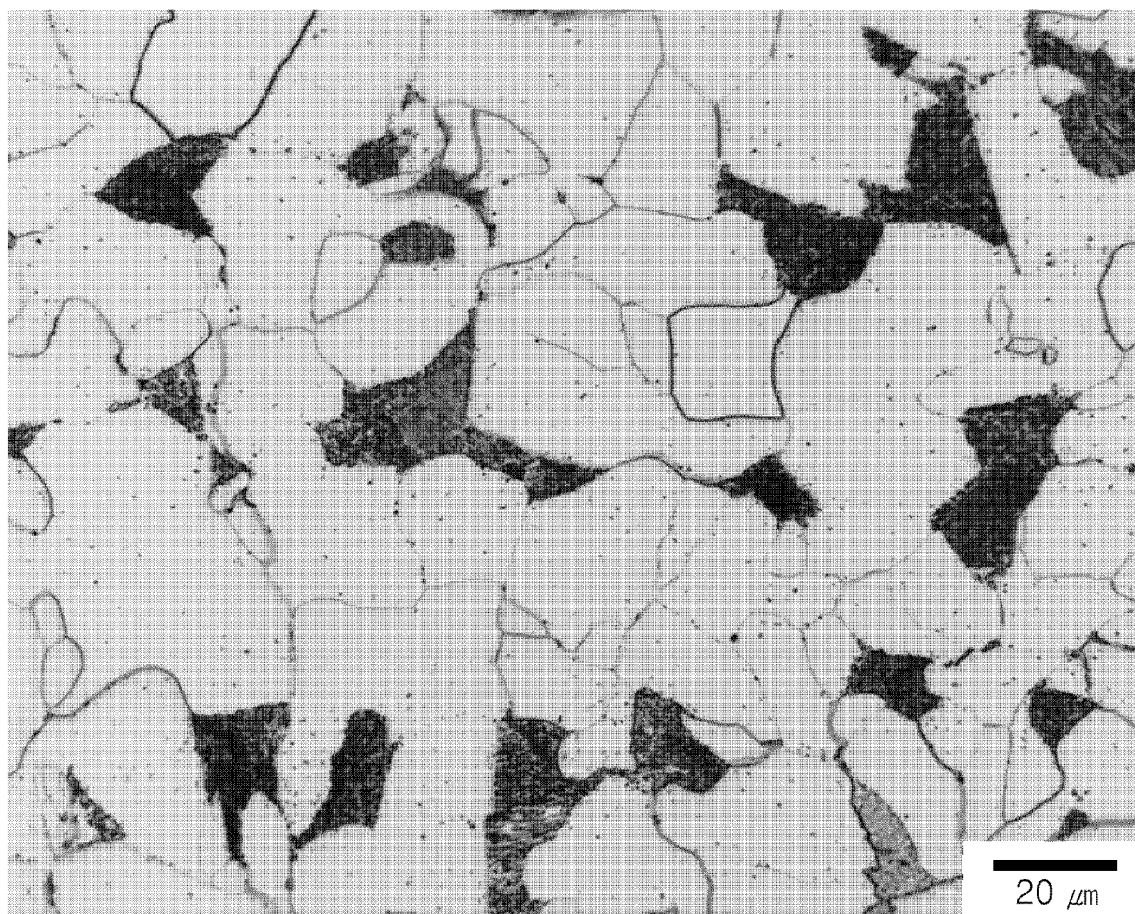
5. The hot-rolled steel sheet of claim 1, wherein a yield strength is 350 MPa or more.

6. The hot-rolled steel sheet of claim 1, wherein a Charpy impact energy at -20 °C is 47 J/cm² or more.

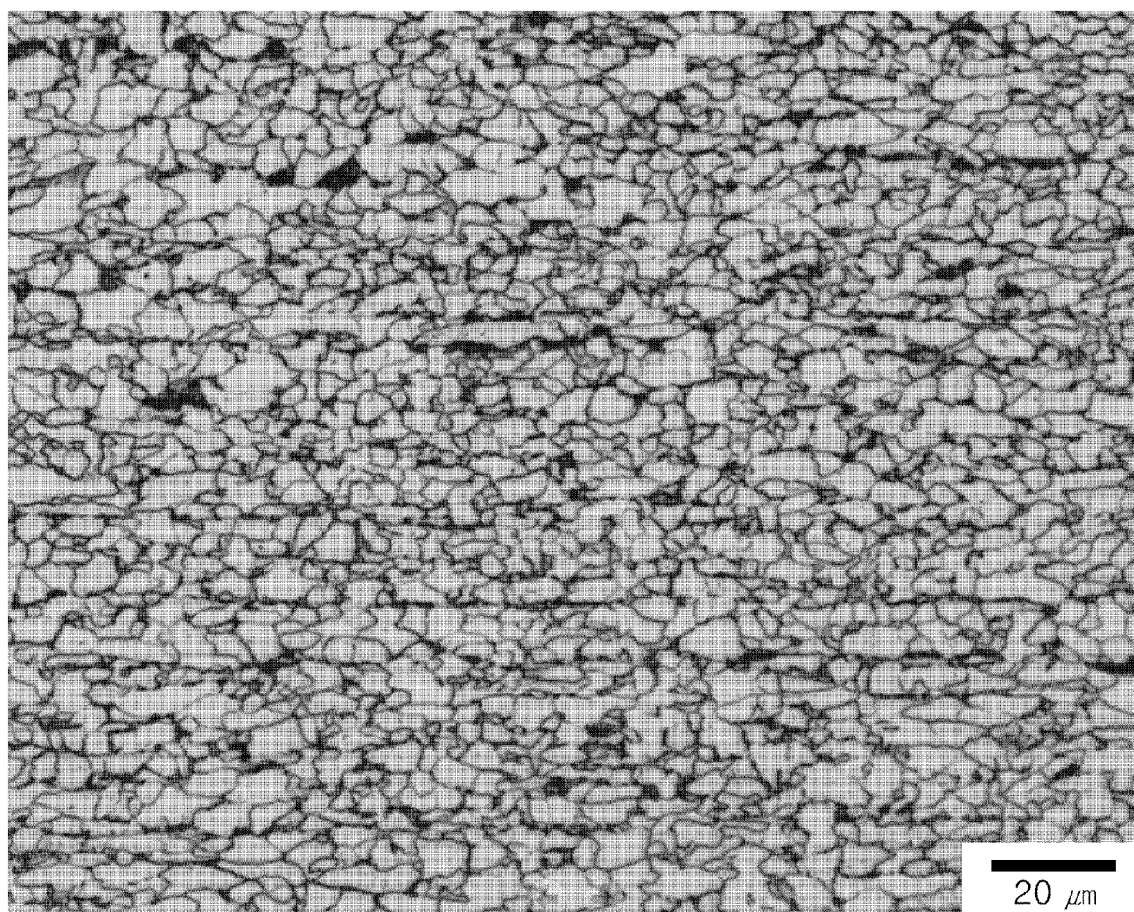
7. The hot-rolled steel sheet of claim 1, wherein, after the hot-rolled steel sheet is processed into a specimen with a length*width*thickness of 80 mm*20 mm*2 mm, a vibration damping ratio measured at a frequency of 1650 Hz in a bending vibration mode is 200*10⁻⁶ or more.

8. The hot-rolled steel sheet of claim 1, wherein, in a welded part formed by welding the hot-rolled steel sheet by means of submerged arc welding,
a Charpy impact energy at -20 °C of the welded part is 47 J/cm² or more, and a fraction of an M (martensite)-A (austenite) phase included in the welded part is 5 area% or less (including 0 area%).

[FIG. 1]



[FIG. 2]



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/020132

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/04(2006.01)i; **C22C 38/02**(2006.01)i; **C22C 38/08**(2006.01)i; **C22C 38/14**(2006.01)i; **C22C 38/12**(2006.01)i;
C22C 38/16(2006.01)i; **C21D 8/02**(2006.01)i; **B61B 13/10**(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); C21D 9/46(2006.01); C22C 38/00(2006.01); C22C 38/24(2006.01);
C22C 38/54(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 sheet), 구리(Cu), 니켈(Ni), 폴리고날 페라이트
(polygonal ferrite), 티타늄(Ti), 니오븀(Nb), 바나듐(V), 결정립(grain)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 10-2001-0112945 A (JFE STEEL CORPORATION) 22 December 2001 (2001-12-22) See paragraph [0137], claims 2-3 and 6 and table 3.	1-8
X	KR 10-2007-0094779 A (NIPPON STEEL CORPORATION) 21 September 2007 (2007-09-21) See claims 1-2 and tables 3-4.	1-2,5
A	WO 2022-210220 A1 (JFE STEEL CORPORATION) 06 October 2022 (2022-10-06) See claims 1-4.	1-8
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A	US 2018-0209007 A1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 26 July 2018 (2018-07-26) See paragraph [0121] and claim 5.	1-8

☐ 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

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“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 10 March 2025	Date of mailing of the international search report 11 March 2025
Name and mailing address of the ISA/KR Korean Intellectual Property Office Government Complex-Daejeon Building 4, 189 Cheongsaro, Seo-gu, Daejeon 35208 Facsimile No. +82-42-481-8578	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2024/020132

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Form PCT/ISA/210 (patent family annex) (July 2022)

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Information on patent family members

International application No.

PCT/KR2024/020132

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