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(71) Applicant: **JFE Steel Corporation**
Tokyo 100-0011 (JP)

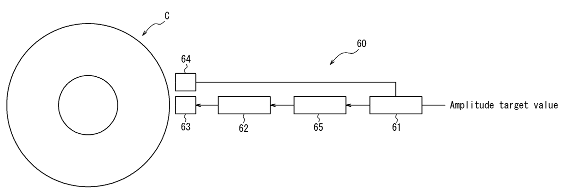
(72) Inventors:
- **TOJI, Yuki**
  Tokyo 100-0011 (JP)
- **ENDOH, Kazuki**
  Tokyo 100-0011 (JP)
- **MINAMI, Hidekazu**
  Tokyo 100-0011 (JP)

(74) Representative: **Hoffmann Eitle**
Patent- und Rechtsanwälte PartmbB
Arabellastraße 30
81925 München (DE)

(54) **DEHYDROGENATION DEVICE, SYSTEM FOR MANUFACTURING STEEL SHEET, AND METHOD FOR MANUFACTURING STEEL SHEET**

(57) Provided are a steel sheet dehydrogenation apparatus, a steel sheet production system, and a steel sheet production method capable of producing a steel sheet excellent in hydrogen embrittlement resistance without changing the mechanical properties of the steel sheet. A dehydrogenation apparatus comprises: a housing configured to house a steel sheet coil obtained by coiling a steel strip; and a vibration application device configured to apply vibration to the steel sheet coil housed in the housing so that the steel sheet coil is caused to vibrate at a frequency of 100 Hz to 100,000 Hz and a maximum amplitude of 10 nm to 500 μm.

FIG. 1



EP 4 357 467 A1

Description

TECHNICAL FIELD

[0001] The present disclosure relates to a dehydrogenation apparatus and a steel sheet production system for producing a steel sheet suitable as a member used in the industrial fields of automobiles, home electric appliances, building materials, etc. The present disclosure especially relates to a dehydrogenation apparatus, a steel sheet production system, and a steel sheet production method for obtaining a steel sheet having low diffusible hydrogen content in steel and excellent hydrogen embrittlement resistance.

BACKGROUND

[0002] As a concern specific to high strength steel sheets, it is known that hydrogen entering into a steel sheet embrittles the steel sheet (hydrogen embrittlement). In the case of annealing a steel sheet using a continuous annealing line or a continuous hot-dip galvanizing line, a H_2-N_2 mixed gas, which is often used as a reducing or non-oxidizing gas, is introduced into an annealing furnace. Due to annealing in the H_2-N_2 mixed gas, hydrogen enters into the steel. Moreover, in steel sheets for automobiles, hydrogen generated due to the corrosion reaction that progresses in the use environment of automobiles enters into the steel. Unless the diffusible hydrogen that has entered into the steel is sufficiently reduced, the diffusible hydrogen is likely to embrittle the steel sheet and cause a delayed fracture.

[0003] Various studies have conventionally been conducted on methods of reducing the diffusible hydrogen content in steel. For example, JP 6562180 B1 (PTL 1) discloses a method of reducing the amount of hydrogen trapped in steel by performing an aging treatment after an annealing treatment and elongation rolling. Another known method of reducing diffusible hydrogen involves leaving a steel sheet after annealing at room temperature for a long time to desorb diffusible hydrogen from the surface of the steel sheet. WO 2019/188642 A1 (PTL 2) discloses a method of reducing the diffusible hydrogen content in steel by holding a cold-rolled and annealed steel sheet in a temperature range of 50 °C or more and 300 °C or less for 1800 seconds or more and 3200 seconds or less.

CITATION LIST

Patent Literature

[0004]

PTL 1: JP 6562180 B1
PTL 2: Specification of WO 2019/188642 A1

SUMMARY

(Technical Problem)

[0005] With the methods described in PTL 1 and PTL 2, there is a possibility that microstructural changes occur due to heating and holding after annealing. It is therefore difficult to apply the methods described in PTL 1 and PTL 2 to other steel sheets. Besides, the method of leaving a steel sheet at room temperature is low in productivity because the steel sheet needs to be left for a long time.

[0006] It could therefore be helpful to provide a steel sheet dehydrogenation apparatus, a steel sheet production system, and a steel sheet production method capable of producing a steel sheet excellent in hydrogen embrittlement resistance without changing the mechanical properties of the steel sheet.

(Solution to Problem)

[0007] Upon careful examination, we discovered that, by applying vibration to a steel sheet at a predetermined frequency and predetermined maximum amplitude, the diffusible hydrogen content in the steel can be reduced to suppress hydrogen embrittlement. Specifically, it was found that microvibration of the steel sheet at a high frequency and small maximum amplitude can sufficiently and efficiently reduce hydrogen in the steel sheet. The mechanism behind this is presumed to be as follows: By forcibly microvibrating the steel sheet, the steel sheet undergoes repeated bending deformation. As a result, the lattice spacing of the surface expands as compared with the mid-thickness part of the steel sheet. Hydrogen in the steel sheet diffuses toward the surface of the steel sheet with wide lattice spacing and low potential energy, and desorbs from the surface.

[0008] The present disclosure is based on these discoveries. We thus provide the following.

[1] A dehydrogenation apparatus comprising: a housing configured to house a steel sheet coil obtained by coiling a steel strip; and a vibration application device configured to apply vibration to the steel sheet coil housed in the housing so that the steel sheet coil is caused to vibrate at a frequency of 100 Hz to 100,000 Hz and a maximum amplitude of 10 nm to 500 μm.

[2] The dehydrogenation apparatus according to [1], wherein the vibration application device comprises an electromagnet having a magnetic pole surface spaced from and facing a surface of the steel sheet coil, and the vibration application device is configured to cause the steel sheet coil to vibrate in response to an external force exerted by the electromagnet on the steel sheet coil.

[3] The dehydrogenation apparatus according to [1], wherein the vibration application device comprises a vibration element configured to contact the steel sheet coil, and the vibration application device is configured to cause the steel sheet coil to be vibrated by the vibration element.

[4] The dehydrogenation apparatus according to any one of [1] to [3], further comprising a heater configured to heat the steel sheet coil while the vibration is applied to the steel sheet coil.

[5] A dehydrogenation apparatus comprising: an uncoiler configured to uncoil a steel sheet coil to feed a steel strip; a sheet passing device configured to pass the steel strip therethrough; a coiler configured to coil the steel strip; and a vibration application device configured to apply vibration to the steel strip being passed through the sheet passing device so that the steel strip is caused to vibrate at a frequency of 100 Hz to 100,000 Hz and a maximum amplitude of 10 nm to 500 μm.

[6] The dehydrogenation apparatus according to [5], wherein the vibration application device comprises an electromagnet having a magnetic pole surface spaced from and facing a surface of the steel strip being passed, and the vibration application device is configured to cause the steel strip to vibrate in response to an external force exerted by the electromagnet on the steel strip.

[7] The dehydrogenation apparatus according to [5], wherein the vibration application device comprises a vibration element configured to contact the steel strip being passed, and the vibration application device is configured to cause the steel strip to be vibrated by the vibration element.

[8] The dehydrogenation apparatus according to any one of [5] to [7], further comprising a heater configured to heat the steel strip while the vibration is applied to the steel strip.

[9] The dehydrogenation apparatus according to any one of [1] to [8], further comprising a vibration damper configured to prevent the vibration from being transmitted to the outside of the dehydrogenation apparatus.

[10] A steel sheet production system comprising: a hot rolling mill configured to subject a steel slab to hot rolling to obtain a hot-rolled steel sheet; a hot-rolled steel sheet coiler configured to coil the hot-rolled steel sheet to obtain a hot-rolled coil; and the dehydrogenation apparatus according to any one of [1] to [9] configured to use the hot-rolled coil as the steel sheet coil.

[11] A steel sheet production system comprising: a cold rolling mill configured to subject a hot-rolled steel sheet to cold rolling to obtain a cold-rolled steel sheet; a cold-rolled steel sheet coiler configured to coil the cold-rolled steel sheet to obtain a cold-rolled coil; and the dehydrogenation apparatus according to any one of [1] to [9] configured to use the cold-rolled coil as the steel sheet coil.

[12] A steel sheet production system comprising: a batch annealing furnace configured to subject a cold-rolled coil or a hot-rolled coil to batch annealing to obtain an annealed coil; and the dehydrogenation apparatus according to any one of [1] to [9] configured to use the annealed coil as the steel sheet coil.

[13] A steel sheet production system comprising: a pre-annealing uncoiler configured to uncoil a cold-rolled coil or a hot-rolled coil to feed a cold-rolled steel sheet or a hot-rolled steel sheet, respectively; a continuous annealing furnace configured to subject the cold-rolled steel sheet or the hot-rolled steel sheet to continuous annealing to obtain an annealed steel sheet; an annealed steel sheet coiler configured to coil the annealed steel sheet to obtain an annealed coil; and the dehydrogenation apparatus according to any one of [1] to [9] configured to use the annealed coil as the steel sheet coil.

[14] A steel sheet production system comprising: a coating or plating apparatus configured to form a coating or plating on a surface of a hot-rolled steel sheet or a cold-rolled steel sheet to obtain a coated or plated steel sheet; a coated or plated steel sheet coiler configured to coil the coated or plated steel sheet to obtain a coated or plated steel sheet coil; and the dehydrogenation apparatus according to any one of [1] to [9] configured to use the coated or plated steel sheet coil as the steel sheet coil.

[15] The steel sheet production system according to [14], wherein the coating or plating apparatus is a hot-dip galvanizing apparatus.

[16] The steel sheet production system according to [14], wherein the coating or plating apparatus includes: a hot-dip galvanizing apparatus; and an alloying furnace following the hot-dip galvanizing apparatus.

[17] The steel sheet production system according to [14], wherein the coating or plating apparatus is an electroplating

apparatus.

[18] A steel sheet production method comprising a vibration application step of applying vibration to a steel sheet coil obtained by coiling a steel strip so that the steel sheet coil is caused to vibrate at a frequency of 100 Hz to 100,000 Hz and a maximum amplitude of 10 nm to 500 μm, to obtain a product coil.

[19] The steel sheet production method according to [18], wherein the vibration application step is performed while holding the steel sheet coil at 300 °C or less.

[20] A steel sheet production method comprising: a step of uncoiling a steel sheet coil to feed a steel strip; a sheet passing step of passing the steel strip; and a step of coiling the steel strip to obtain a product coil, wherein the sheet passing step includes a vibration application step of applying vibration to the steel strip so that the steel strip is caused to vibrate at a frequency of 100 Hz to 100,000 Hz and a maximum amplitude of 10 nm to 500 μm.

[21] The steel sheet production method according to [20], wherein the vibration application step is performed while holding the steel strip at 300 °C or less.

[22] The steel sheet production method according to any one of [18] to [21], comprising: a step of subjecting a steel slab to hot rolling to obtain a hot-rolled steel sheet; and a step of coiling the hot-rolled steel sheet to obtain a hot-rolled coil, wherein the hot-rolled coil is the steel sheet coil.

[23] The steel sheet production method according to any one of [18] to [21], comprising: a step of subjecting a hot-rolled steel sheet to cold rolling to obtain a cold-rolled steel sheet; and a step of coiling the cold-rolled steel sheet to obtain a cold-rolled coil, wherein the cold-rolled coil is the steel sheet coil.

[24] The steel sheet production method according to any one of [18] to [21], comprising a step of subjecting a cold-rolled coil or a hot-rolled coil to batch annealing to obtain an annealed coil, wherein the annealed coil is the steel sheet coil.

[25] The steel sheet production method according to any one of [18] to [21], comprising: a step of uncoiling a cold-rolled coil or a hot-rolled coil to feed a cold-rolled steel sheet or a hot-rolled steel sheet, respectively; a step of subjecting the cold-rolled steel sheet or the hot-rolled steel sheet to continuous annealing to obtain an annealed steel sheet; and a step of coiling the annealed steel sheet to obtain an annealed coil, wherein the annealed coil is the steel sheet coil.

[26] The steel sheet production method according to any one of [18] to [21], comprising: a coating or plating step of forming a coating or plating on a surface of a hot-rolled steel sheet or a cold-rolled steel sheet to obtain a coated or plated steel sheet; and a step of coiling the coated or plated steel sheet to obtain a coated or plated steel sheet coil, wherein the coated or plated steel sheet coil is the steel sheet coil.

[27] The steel sheet production method according to [26], wherein the coating or plating step includes a hot-dip galvanizing step.

[28] The steel sheet production method according to [26], wherein the coating or plating step includes: a hot-dip galvanizing step; and an alloying step following the hot-dip galvanizing step.

[29] The steel sheet production method according to [26], wherein the coating or plating step includes an electroplating step.

[30] The steel sheet production method according to any one of [18] to [29], wherein the product coil is composed of a high strength steel sheet having a tensile strength of 590 MPa or more.

[31] The steel sheet production method according to any one of [18] to [30], wherein the product coil includes a base steel sheet having a chemical composition containing (consisting of), in mass%, C: 0.030 % or more and 0.800 % or less, Si: 0.01 % or more and 3.00 % or less, Mn: 0.01 % or more and 10.00 % or less, P: 0.001 % or more and 0.100 % or less, S: 0.0001 % or more and 0.0200 % or less, N: 0.0005 % or more and 0.0100 % or less, and Al: 2.000 % or less, with the balance being Fe and inevitable impurities.

[32] The steel sheet production method according to [31], wherein the chemical composition further contains, in mass%, at least one element selected from the group consisting of Ti: 0.200 % or less, Nb: 0.200 % or less, V: 0.500 % or less, W: 0.500 % or less, B: 0.0050 % or less, Ni: 1.000 % or less, Cr: 1.000 % or less, Mo: 1.000 % or less, Cu: 1.000 % or less, Sn: 0.200 % or less, Sb: 0.200 % or less, Ta: 0.100 % or less, Ca: 0.0050 % or less, Mg: 0.0050 % or less, Zr: 0.0050 % or less, and REM: 0.0050 % or less.

[33] The steel sheet production method according to any one of [18] to [30], wherein the product coil includes a stainless steel sheet having a chemical composition containing (consisting of), in mass%, C: 0.001 % or more and 0.400 % or less, Si: 0.01 % or more and 2.00 % or less, Mn: 0.01 % or more and 5.00 % or less, P: 0.001 % or more and 0.100 % or less, S: 0.0001 % or more and 0.0200 % or less, Cr: 9.0 % or more and 28.0 % or less, Ni: 0.01 % or more and 40.0 % or less, N: 0.0005 % or more and 0.500 % or less, and Al: 3.000 % or less, with the balance being Fe and inevitable impurities.

[34] The steel sheet production method according to [33], wherein the chemical composition further contains, in mass%, at least one element selected from the group consisting of Ti: 0.500 % or less, Nb: 0.500 % or less, V: 0.500 % or less, W: 2.000 % or less, B: 0.0050 % or less, Mo: 2.000 % or less, Cu: 3.000 % or less, Sn: 0.500 % or less, Sb: 0.200 % or less, Ta: 0.100 % or less, Ca: 0.0050 % or less, Mg: 0.0050 % or less, Zr: 0.0050 % or less,

and REM: 0.0050 % or less.

[35] The steel sheet production method according to any one of [18] to [34], wherein the product coil has a diffusible hydrogen content of 0.50 mass ppm or less.

(Advantageous Effect)

[0009] It is thus possible to produce a steel sheet excellent in hydrogen embrittlement resistance without changing the mechanical properties of the steel sheet.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] In the accompanying drawings:

FIG. 1 is a view illustrating an example of the structure of a vibration application device;
FIG. 2A is a schematic view illustrating an example of installation of electromagnets 63 of the vibration application device 60 relative to a steel sheet coil C in each embodiment of the present disclosure;
FIG. 2B is a schematic view illustrating another example of installation of electromagnets 63 of the vibration application device 60 relative to a steel sheet coil C in each embodiment of the present disclosure;
FIG. 3A is a schematic view illustrating how the magnetic field is generated from an electromagnet 63 in each embodiment of the present disclosure;
FIG. 3B is a schematic view illustrating how the magnetic field is generated from an electromagnet 63 in each embodiment of the present disclosure;
FIG. 4 is a schematic view illustrating another example of the structure of the vibration application device;
FIG. 5A is a perspective view schematically illustrating an example of the structure of a dehydrogenation apparatus equipped with the vibration application device 60 according to Embodiment 1;
FIG. 5B is a view of the dehydrogenation apparatus as seen from a side surface a;
FIG. 5C is a view of an example of the dehydrogenation apparatus as seen from a side surface b;
FIG. 5D is a view of another example of the dehydrogenation apparatus as seen from the side surface b;
FIG. 6 is an overview diagram illustrating an example of the structure of a dehydrogenation apparatus equipped with the vibration application device 70 according to Embodiment 1;
FIG. 7 is a view illustrating an example of the structure of a dehydrogenation apparatus equipped with the vibration application device 60 according to Embodiment 2 as seen from the coiling axial direction of a steel sheet coil; and
FIG. 8 is a view illustrating an example of the structure of a dehydrogenation apparatus equipped with the vibration application device 70 according to Embodiment 2 as seen from the coiling axial direction of a steel sheet coil.

DETAILED DESCRIPTION

[0011] Embodiments of the present disclosure will be described below, although the present disclosure is not limited to such embodiments. Herein, each numeric value range expressed in the form of "A to B" denotes a range that includes values A and B as its lower and upper limits. Herein, the term "steel sheet" is a general term that includes a hot-rolled steel sheet, a cold-rolled steel sheet, an annealed steel sheet obtained by annealing the hot-rolled steel sheet or the cold-rolled steel sheet, and a coated or plated steel sheet obtained by forming a coating or plating on the surface of the hot-rolled steel sheet, cold-rolled steel sheet, or annealed steel sheet. The shape of the "steel sheet" is not limited, and includes both a steel sheet coil and a steel strip fed as a result of uncoiling a steel sheet coil.

[0012] A dehydrogenation apparatus according to the present disclosure applies vibration to a steel sheet at a predetermined frequency and maximum amplitude to reduce the diffusible hydrogen content in the steel. This dehydrogenation apparatus does not need a heating treatment for the steel sheet, and thus can reduce the diffusible hydrogen content in the steel without changing the microstructural properties of the steel sheet.

[0013] A steel sheet production method according to the present disclosure applies vibration to a steel sheet so that the steel sheet is caused to vibrate at a frequency of 100 Hz to 100,000 Hz and a maximum amplitude of 10 nm to 500 μm. This steel sheet production method does not need a heating treatment for the steel sheet, and thus can reduce the diffusible hydrogen content in the steel without changing the microstructural properties of the steel sheet.

[0014] Although the reason why applying vibration to a steel sheet improves the hydrogen embrittlement resistance of the steel sheet is not clear, we presume the reason as follows:

As a result of applying vibration to the steel sheet under predetermined conditions, the steel sheet is forcibly vibrated. Due to the bending deformation caused by the forced vibration, the lattice spacing of the steel sheet repeats expansion (tension) and contraction (compression) in the thickness direction. Since diffusible hydrogen in steel is induced to diffuse to the tensile side with lower potential energy, the diffusion of diffusible hydrogen is promoted with the expansion and contraction of the lattice spacing, and the diffusion path of diffusible hydrogen connecting the inside and the surface of the steel sheet is forcibly created. Diffusible hydrogen whose diffusion path has been forcibly formed escapes through the surface to the outside of the steel sheet, which is more advantageous in terms of potential energy, at the timing when the lattice spacing near the surface of the steel sheet expands. In this way, the vibration applied to the steel sheet under the predetermined conditions reduce the diffusible hydrogen in the steel sufficiently and efficiently, so that hydrogen embrittlement of the steel sheet can be suppressed favorably and easily.

[0015] The following will separately describe (1) a dehydrogenation apparatus and a steel sheet production method that apply vibration to a steel sheet coil, and (2) a dehydrogenation apparatus and a steel sheet production method that uncoil a steel sheet coil to feed a steel sheet, apply vibration to the steel sheet, and recoil the steel sheet.

<Embodiment 1>

[0016] A dehydrogenation apparatus according to this embodiment comprises: a housing configured to house a steel sheet coil C obtained by coiling a steel strip; and a vibration application device configured to apply vibration to the steel sheet coil housed in the housing so that the steel sheet coil is caused to vibrate at a frequency of 100 Hz to 100,000 Hz and a maximum amplitude of 10 nm to 500 μm. In various steps in steel sheet production, a steel strip is coiled to form a steel sheet coil.

[0017] A steel sheet production method according to this embodiment comprises a vibration application step of applying vibration to a steel sheet coil obtained by coiling a steel strip so that the steel sheet coil is caused to vibrate at a frequency of 100 Hz to 100,000 Hz and a maximum amplitude of 10 nm to 500 μm. In various steps in steel sheet production, a steel strip is coiled to form a steel sheet coil.

[0018] With the dehydrogenation apparatus and the steel sheet production method according to this embodiment, by applying vibration to the steel sheet coil, the diffusible hydrogen content in the steel can be reduced and a steel sheet excellent in hydrogen embrittlement resistance can be obtained. In particular, in the steel sheet coil, the steel strip is subjected to bending deformation and the lattice spacing on the radially outer surface of the steel strip is expanded, and therefore the diffusion path of hydrogen is likely to be formed radially outward. In this embodiment, by applying vibration to the steel sheet coil, the steel strip in a state in which the lattice spacing on the radially outer surface is expanded is further subjected to minute bending deformation, with it being possible to reduce diffusible hydrogen in the steel more favorably.

[[Vibration application device]]

(Vibration application device 60)

[0019] A vibration application device can be used for application of vibration. For example, the vibration application device may be configured to cause the steel sheet coil to vibrate in response to an external force (attractive force) exerted by an electromagnet on the steel sheet coil. FIG. 1 illustrates an example of the structure of a vibration application device. For example, a vibration application device 60 includes a controller 61, an amplifier 62, an electromagnet 63, a vibration detector 64, and a power supply 65. With reference to FIGS. 3A and 3B, for example, the vibration application device 60 has an electromagnet 63 that includes a magnet 63A and a coil 63B wound around the magnet 63A. The electromagnet 63 has a magnetic pole surface 63A1 that is spaced from and facing a surface of the steel sheet coil. The "surface of the steel sheet coil" herein refers to the surface of the steel sheet located on the outermost periphery in the radial direction of the steel sheet coil C.

[0020] The electromagnet 63 has the magnetic pole surface 63A1 that is spaced from and facing a surface of the steel sheet coil C. It is preferable that the electromagnet 63 have the magnetic pole surface 63A1 spaced from and facing a surface of the steel sheet coil C such that the magnetic pole surface 63A1 is perpendicular to the radial direction of the steel sheet coil C. This setup makes the magnetic field lines extending along the radial direction of the steel sheet coil C and enables an attractive force to be applied to the steel sheet coil C, as illustrated in FIGS. 3A and 3B. The shape and installation of such electromagnets can be seen, for example, in FIGS. 2A and 2B.

[0021] In FIG. 2A, rectangular-shaped electromagnets 63 are arranged to extend along the sheet transverse direction above a surface of the steel sheet coil C with a predetermined spacing from each other. This setup allows an external force (attractive force) to be applied uniformly in the width direction of the surface of the steel sheet coil C, thus achieving uniform vibration in the width direction. Then, arranging a plurality of such electromagnets 63 in the sheet passing direction allows sufficient time to apply vibration to the steel sheet coil C. As seen from FIG. 2A, each electromagnet 63 has a magnet 63A and a coil 63B wound around it, and the axial direction of the coil 63B is aligned with the thickness direction of the cold-rolled steel sheet S. In this case, depending on the direction of the current flowing in the coil 63B, the magnetic pole surface 63A1 facing the steel sheet coil C becomes N-pole as illustrated in FIG. 3A, or S-pole as illustrated in FIG. 3B.

[0022] In FIG. 2B, a plurality of cylindrical electromagnets 63 are arranged at predetermined intervals along the sheet transverse direction so that their bottom pole surfaces are spaced from and facing a surface of the steel sheet coil C. This setup allows an external force (attractive force) to be applied uniformly in the width direction of the surface of the steel sheet coil C, thus achieving uniform vibration in the width direction. Then, arranging multiple rows of such cylindrical-shaped electromagnets 63 along the sheet passing direction allows sufficient time to apply vibration to the steel sheet coil C. As seen from FIG. 2B, each electromagnet 63 has a cylindrical magnet and a coil wound around it, and the axial direction of the coil is aligned with the thickness direction of the steel sheet coil C. In this case, depending on the direction of the current flowing in the coil, the magnetic pole surface 63A1 facing the steel sheet coil C becomes N-pole as illustrated in FIG. 3A, or S-pole as illustrated in FIG. 3B.

[0023] In order to uniformly apply vibration to the entire surface of the steel sheet coil C, it is preferable that a plurality of electromagnets 63 be arranged at uniform intervals along the circumferential direction of the steel sheet coil C. For example, a plurality of electromagnets 63 may be arranged along the circumferential direction of the steel sheet coil C with a spacing of 1° to 30° from each other at the center angle of the steel sheet coil C.

[0024] In FIGS. 3A and 3B, an external force (attractive force) is exerted on the surface of the steel sheet coil C when an electric current is applied to the electromagnets 63. The current applied to the electromagnets 63 is either a pulsed direct current or a continuous alternating current. When a pulsed direct current is applied to the electromagnets 63, the steel sheet coil C vibrates due to the intermittent attractive force exerted on the cold-rolled steel sheet S. When a continuous alternating current is applied to the electromagnets 63, each time the direction of the current changes, each magnetic pole surface 63A1 facing the steel sheet coil C switches between the N and S poles, yet an external force (attractive force) is always exerted on the steel sheet coil. In the case of alternating current, the magnitude of the external force (attractive force) exerted on the steel sheet coil varies with changes in the current value over time, causing the steel sheet coil C to vibrate.

[0025] The vibration detector 64 illustrated in FIG. 1 is a laser displacement meter or laser Doppler vibrometer positioned at a predetermined distance from the surface of the steel sheet coil C, and is capable of measuring the frequency and amplitude of vibration of the surface of the steel sheet coil C. By placing the vibration detector 64 at the same height as the electromagnets 63 relative to the steel sheet coil, the maximum amplitude of vibration of the steel sheet coil C can be measured with the vibration detector 64. The frequency and maximum amplitude detected by the vibration detector 64 are output to the controller 61. The controller 61 receives the frequency and maximum amplitude values output from the vibration detector 64, compares them with the set values, performs operations such as PID operations on the deviations to determine the frequency (frequency of the pulsed direct current or continuous alternating current) and current value for the electromagnets 63 such that the cold-rolled steel sheet S is caused to vibrate at a predetermined frequency and maximum amplitude, as well as the current value to be provided to the amplifier 62 in consideration of the amplification rate of the amplifier 62, and provides command values to the power supply 65. The power supply 65 is a power supply for passing current through the coils of the electromagnets 63. The power supply 65 receives the command values input from the controller 61 and provides a current at a predetermined frequency and current value to the amplifier 62. The amplifier 62 amplifies the current values provided by the power supply 65 at a predetermined amplification rate and provides the command values to the electromagnets 63. In this way, a current at the predetermined frequency and current value flows through the electromagnets 63, enabling the steel sheet coil C to vibrate at the predetermined frequency and maximum amplitude.

(Vibration Application Device 70)

[0026] In another example, the vibration application device comprises a vibration element 72 configured to contact a surface of the steel sheet coil C, and the vibration application device is configured to cause the steel sheet coil C to be vibrated by the vibration element 72. FIG. 4A illustrates the other example of the structure of the vibration application device. With reference to FIG. 4A, a vibration application device 70 includes controllers 71, vibration elements 72, and vibration detectors 73. The vibration application device 70 comprises the vibration elements 72 configured to contact the steel sheet coil C, and the vibration application device 70 is configured to cause the steel sheet coil C to be vibrated by the vibration elements 72.

[0027] Each vibration element 72 may be any general piezoelectric element without limitation on its shape and installation. However, for example, as illustrated in FIG. 4B, each vibration element 72 may be a planner vibration element with its length in the sheet transverse direction of the steel sheet coil C that is brought into surface contact with the surface of the steel sheet coil C to vibrate the steel sheet coil C. In order to uniformly apply vibration to the entire surface of the steel sheet coil C, it is preferable that a plurality of such vibration elements 72 be arranged at uniform intervals along the circumferential direction of the steel sheet coil C. For example, a plurality of vibration elements 72 may be arranged along the circumferential direction of the steel sheet coil C with a spacing of 1° to 30° from each other at the center angle of the steel sheet coil C.

[0028] The vibration detectors 73 illustrated in FIG. 4A are laser displacement meters or laser Doppler vibrometers positioned above the surface of the steel sheet coil C with a predetermined spacing from each other, and are capable of measuring the frequency and amplitude of vibration of the steel sheet coil C. By placing the vibration detectors 73 at the same height as the vibration elements 72 relative to the steel sheet coil C, the maximum amplitude of vibration of the steel sheet coil C can be measured with the vibration detectors 73. The frequency and maximum amplitude detected by each vibration detectors 73 are output to the controllers 71. The controllers 71 receive the frequency and maximum amplitude values output from the vibration detectors 73, compare them with the set values, perform operations such as PID operations on the deviations to determine the frequency and current value of a pulsed direct current to flow through the vibration elements 72 such that the steel sheet coil C is caused to vibrate at a predetermined frequency and maximum amplitude, and control the power supplies (not illustrated) to provide a pulsed direct current at a predetermined frequency and current value to the vibration elements 72. In this way, the vibration elements 72 are caused to vibrate at the predetermined frequency and amplitude, enabling the steel sheet coil C to vibrate at the predetermined frequency and maximum amplitude.

[[Dehydrogenation apparatus]]

[0029] FIGS. 5A to 5D illustrate an example of a dehydrogenation apparatus for reducing diffusible hydrogen in the steel by applying vibration to a steel sheet coil C using the vibration application device 60. FIG. 5A is a perspective view of a dehydrogenation apparatus 300a. Only the rows of electromagnets 63 on the frontmost side as seen from a side surface a of the dehydrogenation apparatus 300a are illustrated in FIG. 5A. FIG. 5B is a view of the dehydrogenation apparatus 300a as seen from the side surface a. As illustrated in FIGS. 5A and 5B, the dehydrogenation apparatus 300a comprises a housing 80 configured to house steel sheet coils C, and electromagnets 63 configured to apply vibration to the steel sheet coils C housed in the housing 80. The number of electromagnets 63 and the arrangement of the electromagnets 63 are not limited. In the example in FIGS. 2A and 2B, a plurality of electromagnets 63 are arranged so as to surround the steel sheet coils C. Although not illustrated in FIGS. 5A to 5D, each electromagnet 63 is coupled with an amplifier 62, a power supply 65, and a controller 61, which controller is further coupled with a vibration detector 64, so that vibration is applied from the electromagnet 63 to the steel sheet coil C. As a result of arranging the plurality of electromagnets 63 so as to surround the steel sheet coil C, vibration can be applied uniformly to the steel sheet coil C. In the case where the electromagnets 63 are provided so as to surround the steel sheet coil C as illustrated in FIG. 5A, it is believed that the coil surface of the steel sheet coil C is caused to vibrate by the electromagnets 63. In the steel sheet coil C whose coil surface is vibrated, the vibration propagates toward the inner circumference of the coil through the air existing between the steel sheets in the steel sheet coil C or the vibration propagates from the outermost surface of the coil directly toward the inner circumference of the coil, and eventually the vibration propagates to the innermost part of the coil. As illustrated in the drawing, the housing 80 may be capable of housing a plurality of steel sheet coils C.

[0030] From the viewpoint of uniformly applying vibration to the entire surface of the steel sheet coil C, it is preferable to arrange a plurality of electromagnets 63 in the height direction and the width direction of the inner walls of the dehydrogenation apparatus 300a so as to surround the steel sheet coil C. FIG. 5C is a view of an example of the dehydrogenation apparatus seen from a side surface b. As illustrated in FIG. 5C, electromagnets 63 may be arranged at uniform intervals in the height direction and the width direction of the side surface b. FIG. 5D is a view of another example of the dehydrogenation apparatus seen from the side surface b. The electromagnets 63 may be in any shape as long as they are capable of applying vibration to the steel sheet coil C. For example, the electromagnets 63 may be rectangular tubes with a rectangular cross-sectional shape, as illustrated in FIG. 5D. Moreover, electromagnets 63 may be inserted into the hollow portion defined by the steel sheet coil C to apply vibration to the steel sheet coil C from inside.

[0031] Since diffusible hydrogen is also released from the end surfaces of the steel sheet coil C, the efficiency of reducing the diffusible hydrogen content is lower in the steel sheet transverse center part than in the steel sheet transverse edge part of the steel sheet coil C. Hence, it is particularly preferable to provide electromagnets 63 around the steel sheet transverse center part of the steel sheet coil C.

[0032] A coil holder 90 is provided in the dehydrogenation apparatus 300a as appropriate, as illustrated in the drawing. The form of the coil holder 90 is not limited. In the case where the steel sheet coil C is placed so that the coiling axial direction of the steel sheet coil C will be parallel to the floor of the dehydrogenation apparatus 300a, the coil holder 90 may be a pair of rod-shaped members that sandwich the steel sheet coil C from both sides in order to prevent the steel sheet coil C from rolling within the dehydrogenation apparatus 300a, as illustrated in FIG. 5A. The coil holder 90 may be a pair of rod-shaped members having a concave arcuate upper surface along the arc drawn by the outermost periphery of the steel sheet coil C, as illustrated in FIG. 5A. Although not illustrated, the steel sheet coil C may be placed so that the coiling axial direction will be parallel to the floor of the dehydrogenation apparatus 300a.

[0033] From the viewpoint of uniformly applying vibration to the entire surface of the steel sheet coil C, it is preferable to arrange a plurality of electromagnets 63 in the height direction and the width direction of the inner walls of the dehydrogenation apparatus 300a so as to surround the steel sheet coil C. FIG. 5C is a view of an example of the dehydrogenation apparatus seen from a side surface b. As illustrated in FIG. 5C, electromagnets 63 may be arranged at uniform intervals in the height direction and the width direction of the side surface b. FIG. 5D is a view of another example of the dehydrogenation apparatus seen from the side surface b. The electromagnets 63 may be in any shape as long as they are capable of applying vibration to the steel sheet coil C. For example, the electromagnets 63 may be rectangular tubes with a rectangular cross-sectional shape, as illustrated in FIG. 5D. Moreover, electromagnets 63 may be inserted into the hollow portion defined by the steel sheet coil C to apply vibration to the steel sheet coil C from inside.

[0034] Since diffusible hydrogen is also released from the end surfaces of the steel sheet coil C, the efficiency of reducing the diffusible hydrogen content is lower in the steel sheet transverse center part than in the steel sheet transverse edge part of the steel sheet coil C. Hence, it is particularly preferable to provide electromagnets 63 around the steel sheet transverse center part of the steel sheet coil C.

[0035] A coil holder 90 is provided in the dehydrogenation apparatus 300a as appropriate, as illustrated in the drawing. The form of the coil holder 90 is not limited. In the case where the steel sheet coil C is placed so that the coiling axial direction of the steel sheet coil C will be parallel to the floor of the dehydrogenation apparatus 300a, the coil holder 90 may be a pair of rod-shaped members that sandwich the steel sheet coil C from both sides in order to prevent the steel sheet coil C from rolling within the dehydrogenation apparatus 300a, as illustrated in FIG. 5A. The coil holder 90 may be a pair of rod-shaped members having a concave arcuate upper surface along the arc drawn by the outermost periphery of the steel sheet coil C, as illustrated in FIG. 5A. Although not illustrated, the steel sheet coil C may be placed so that the coiling axial direction will be parallel to the floor of the dehydrogenation apparatus 300a.

[0036] FIG. 6 illustrates an example of a dehydrogenation apparatus for reducing diffusible hydrogen in the steel by applying vibration to a steel sheet coil C using the vibration application device 70. FIG. 6 is a view of the dehydrogenation apparatus 300a as seen from an end surface of the steel sheet coil C. As illustrated in FIG. 6, the dehydrogenation apparatus 300a comprises a housing 80 configured to house a steel sheet coil C, and vibration elements 72 configured to apply vibration to the steel sheet coil C housed in the housing 80. Each vibration element 72 is configured to contact the steel sheet coil C to apply vibration thereto. Although not illustrated, in each vibration application device 70, each vibration element 72 is coupled to a controller 71 and a vibration detector 73 so that vibration is applied from the vibration element 72 to the steel sheet coil C. In the dehydrogenation apparatus 300a in which vibration is applied using the vibration application device 70, as illustrated in FIG. 6, the vibration elements 72 are arranged along the surface of the steel sheet coil C so that the vibration elements 72 are brought into surface contact with the surface of the steel sheet coil C in the housing 80. There is no particular limitation on the form of arrangement of the vibration elements 72 along the surface of the steel sheet coil C in the dehydrogenation apparatus 300a. However, for example, scaffolds can be provided in the housing 80 to cover the surface of the steel sheet coil C, and the vibration elements 72 can be fixed to the scaffolds at uniform intervals.

[0037] From the viewpoint of uniformly applying vibration to the entire surface of the steel sheet coil C, it is preferable that the vibration elements 72 be arranged at uniform intervals along the sheet transverse direction of the steel sheet coil C. Alternatively, as illustrated in FIG. 4B, it is preferable to use vibration elements 72 that extend along the sheet transverse direction of the steel sheet coil C.

[0038] Since diffusible hydrogen is also released from the end surfaces of the steel sheet coil C, the efficiency of reducing the diffusible hydrogen content is lower in the steel sheet transverse center part than in the steel sheet transverse edge part of the steel sheet coil C. Hence, it is particularly preferable to provide vibration elements 72 around the steel sheet transverse center part of the steel sheet coil C.

[0039] A coil holder 90 is provided in the dehydrogenation apparatus 300a as appropriate, as illustrated in the drawing. Since the details of the coil holder 90 have been described above, the description is omitted here.

(Frequency of vibration)

[0040] It is important that the frequency of vibration of the steel sheet coil C be 100 Hz or more, from the viewpoint of further promoting the diffusion of hydrogen. When the frequency is lower than 100 Hz, the effect of desorbing hydrogen contained in the cold-rolled steel sheet S cannot be obtained. From this perspective, the frequency is 100 Hz or more, preferably 500 Hz or more, and more preferably 1,000 Hz or more. Note that the steel sheet coil C may vibrate unintentionally. However, in such cases, the frequency of vibration of the steel sheet coil C is at most about 20 Hz, and the effect of desorbing the hydrogen contained in the steel sheet coil C cannot be obtained. On the other hand, if the frequency is excessively high, sufficient time to expand the lattice spacing in the steel sheet cannot be ensured, and the effect of desorbing hydrogen cannot be obtained. From this perspective, it is important to keep the frequency at or below 100,000 Hz, preferably at or below 80,000 Hz, and more preferably at or below 50,000 Hz. The frequency of vibration of the steel sheet coil C can be measured by the vibration detector 64 illustrated in FIG. 1 or the vibration detectors 73 illustrated in FIG. 4A. The frequency of vibration of the steel sheet coil C can be adjusted by controlling the frequency of the pulsed direct current or continuous alternating current in the case of the vibration application device 60 illustrated in FIG. 1, or by controlling the frequency of vibration of the vibration elements 72 in the case of the vibration application device 70 illustrated in FIGS. 4A and 4B.

(Maximum amplitude of vibration)

[0041] If the maximum amplitude of the steel sheet coil C is less than 10 nm, the lattice spacing on the surface of the steel sheet does not sufficiently expand and the diffusion of hydrogen is not sufficiently facilitated, and thus the effect of desorbing the hydrogen contained in the steel sheet coil C cannot be obtained. Therefore, it is important that the maximum amplitude of the steel sheet coil C be 10 nm or more, preferably 100 nm or more, and more preferably 500 nm or more. If the maximum amplitude of the steel sheet coil C is more than 500 μm, the strain on the surface of the steel sheet increases and plastic deformation occurs, which ends up trapping hydrogen. Accordingly, the effect of desorbing the hydrogen contained in the steel sheet coil C cannot be obtained. From this perspective, it is important that the maximum amplitude of the steel sheet coil C be 500 μm or less, preferably 400 μm or less, and more preferably 300 μm or less. The steel sheet coil C naturally vibrates during the sheet passage process, or it vibrates, for example, when exposed to gas from the gas wiping device 32. However, in these cases, the maximum amplitude of the steel sheet coil C is at least more than 0.5 mm, and the effect of desorbing the hydrogen contained in the steel sheet coil C cannot be obtained. The maximum amplitude of the steel sheet coil C can be measured by the vibration detector 64 illustrated in FIG. 1 or the vibration detectors 73 illustrated in FIG. 4A. The maximum amplitude of the steel sheet coil C can be adjusted by controlling the amount of current flowing through the electromagnets 63 in the case of the vibration application device 60 illustrated in FIG. 1, or by controlling the amplitude of vibration of the vibration elements 72 in the case of the vibration application device 70 illustrated in FIGS. 4A and 4B.

(Vibration application time)

[0042] The vibration application time for the steel sheet coil C is not limited. In this embodiment, vibration is applied to the steel sheet coil after hot rolling or after cold rolling, and accordingly there is no constraint on the irradiation time unlike in the case where vibration is applied to the steep strip being passed. Since a longer vibration application time is expected to contribute to reduction of more diffusible hydrogen, the vibration application time is preferably 1 minute or more. The vibration application time is more preferably 30 minutes or more, and further preferably 60 minutes or more. From the viewpoint of productivity, the vibration application time is preferably 30,000 minutes or less, more preferably 10,000 minutes or less, and further preferably 1,000 minutes or less. The vibration application time can be controlled, for example, by controlling the drive time of the vibration application device 60 by the controller.

[[Heater]]

[[Holding temperature of steel sheet coil]]

[0043] The dehydrogenation apparatus 300a may further comprise a heater configured to heat the steel sheet coil C while the vibration is applied to the steel sheet coil C. The temperature of the steel sheet coil C in the vibration application step is not limited. According to this embodiment, diffusible hydrogen in the steel can be reduced even without heating and holding the steel sheet coil C. By applying vibration to the steel sheet coil C while heating the steel sheet coil C by the heater, however, the hydrogen diffusion rate can be further increased, as a result of which the diffusible hydrogen content in the steel can be further reduced. Accordingly, the temperature of the steel sheet coil C when applying vibration is preferably 30 °C or more, more preferably 50 °C or more, and further preferably 100 °C or more. No upper limit is placed on the temperature of the steel sheet coil C in the vibration application step, but the temperature of the steel sheet coil C in the vibration application step is preferably 300 °C or less except in the case of performing vibration application during batch annealing as described later, from the viewpoint of appropriately preventing the microstructural changes of the steel sheet coil C. In this embodiment, the temperature of the steel sheet coil C when applying vibration is based on the temperature at a 1/2 position in the radial direction of the steel sheet coil. The temperature at the 1/2 position in the radial direction of the steel sheet coil can be measured by directly inserting a thermocouple at the 1/2 position in the radial direction of the steel sheet coil and measuring the temperature of the steel strip present at the 1/2 position in the radial direction. The method of heating the steel sheet coil C may be a typical method, such as a method of installing a heater on the side wall of the housing or a method of blowing high-temperature air generated outside to the housing 80 and circulating it in the housing.

[0044] The dehydrogenation apparatus 300a according to this embodiment may further comprise a vibration damper configured to prevent the vibration from being transmitted to the outside of the dehydrogenation apparatus 300a. The vibration damper may be, for example, a vibration damping material provided so as to surround the inner wall of the housing 80.

[0045] According to this embodiment, the diffusible hydrogen content in the product coil C obtained after the vibration application can be reduced to 0.5 mass ppm or less. As a result of the diffusible hydrogen content in the product coil C being reduced to 0.5 mass ppm or less, hydrogen embrittlement of the steel sheet can be prevented. The diffusible hydrogen content in the steel after the vibration application is preferably 0.3 mass ppm or less, and further preferably 0.2 mass ppm or less.

[0046] The diffusible hydrogen content in the product coil C is measured in the following manner: A test piece of 30 mm in length and 5 mm in width is collected from the 1/2 position in the radial direction of the product coil. In the case where the steel sheet is a hot-dip galvanized steel sheet or a galvannealed steel sheet, the hot-dip galvanized layer or the galvannealed layer of the test piece is removed by grinding or alkali. After this, the amount of hydrogen released from the test piece is measured by thermal desorption spectrometry (TDS). Specifically, the test piece is continuously heated from room temperature to 300 °C at a heating rate of 200 °C/h and then cooled to room temperature, and the cumulative amount of hydrogen released from the test piece from room temperature to 210 °C is measured and taken to be the diffusible hydrogen content in the product coil C.

[0047] Application examples of this embodiment will be described in detail below.

[[Hot-rolled steel sheet]]

[0048] The dehydrogenation apparatus 300a and the steel sheet production method according to this embodiment can be applied to the production of hot-rolled steel sheets.

[0049] A steel sheet production system according to this application example comprises: a hot rolling mill configured to subject a steel slab to hot rolling to obtain a hot-rolled steel sheet; a hot-rolled steel sheet coiler configured to coil the hot-rolled steel sheet to obtain a hot-rolled coil; and the steel sheet dehydrogenation apparatus configured to use the hot-rolled coil as the steel sheet coil C. The hot rolling mill subjects a steel slab having a known chemical composition to hot rolling including rough rolling and finish rolling, to obtain a hot-rolled steel sheet. The hot-rolled steel sheet coiler coils the hot-rolled steel sheet to obtain a hot-rolled coil. The dehydrogenation apparatus 300a applies vibration to the hot-rolled coil as the steel sheet coil C under the foregoing conditions. As a result of the vibration application, the diffusible hydrogen content in the steel can be reduced and a hot-rolled steel sheet excellent in hydrogen embrittlement resistance can be obtained. The obtained hot-rolled steel sheet may be further subjected to cold rolling to obtain a cold-rolled steel sheet.

[0050] A steel sheet production method according to this application example comprises: a step of subjecting a steel slab to hot rolling to obtain a hot-rolled steel sheet; and a step of coiling the hot-rolled steel sheet to obtain a hot-rolled coil, wherein the hot-rolled coil is the steel sheet coil. The hot-rolled coil production method before vibration application is not limited, and a steel slab having a known chemical composition may be subjected to hot rolling including rough rolling and finish rolling to obtain a hot-rolled steel sheet, and the hot-rolled steel sheet may be coiled according to a known method to obtain a hot-rolled coil. As a result of the vibration being applied to the hot-rolled coil under the foregoing conditions, the diffusible hydrogen content in the steel can be reduced and a hot-rolled steel sheet excellent in hydrogen embrittlement resistance can be obtained. The obtained hot-rolled steel sheet may be further subjected to cold rolling to obtain a cold-rolled steel sheet.

[[Cold-rolled steel sheet]]

[0051] The dehydrogenation apparatus 300a and the steel sheet production method according to this embodiment can also be applied to the production of cold-rolled steel sheets.

[0052] A steel sheet production system according to this application example comprises: a cold rolling mill configured to subject a hot-rolled steel sheet to cold rolling to obtain a cold-rolled steel sheet; a cold-rolled steel sheet coiler configured to coil the cold-rolled steel sheet to obtain a cold-rolled coil; and the dehydrogenation apparatus 300a configured to use the cold-rolled coil as the steel sheet coil C. The cold rolling mill subjects a known hot-rolled steel sheet optionally to hot-rolled sheet annealing, and subjects the hot-rolled steel sheet after the hot rolling or after the hot-rolled sheet annealing to cold rolling once, or twice or more with intermediate annealing being performed therebetween, to obtain a cold-rolled steel sheet having a final thickness. The cold-rolled steel sheet coiler coils the cold-rolled steel sheet after the cold rolling to obtain a cold-rolled coil by a known method. The dehydrogenation apparatus 300a applies vibration to the cold-rolled coil as the steel sheet coil C under the foregoing conditions. As a result of the vibration application, the diffusible hydrogen content in the steel can be reduced and a cold-rolled steel sheet excellent in hydrogen embrittlement resistance can be obtained. The steel sheet production system may further comprise the dehydrogenation apparatus 300a configured to apply vibration to a hot-rolled coil obtained by coiling the hot-rolled steel sheet after the hot rolling under the foregoing conditions. The hot-rolled coil after the vibration application is then uncoiled to feed the hot-rolled steel sheet, the hot-rolled steel sheet is subjected to cold rolling to obtain a cold-rolled coil, and the vibration is applied to the cold-rolled coil by the dehydrogenation apparatus 300a. Thus, the diffusible hydrogen content in the steel can be further reduced, and a steel sheet particularly excellent in hydrogen embrittlement resistance can be obtained.

[0053] A steel sheet production method according to this application example comprises: a step of subjecting a hot-rolled steel sheet to cold rolling to obtain a cold-rolled steel sheet; and a step of coiling the cold-rolled steel sheet to obtain a cold-rolled coil, wherein the cold-rolled coil is the steel sheet coil. The cold-rolled coil production method before vibration application is not limited. For example, a steel slab having a known chemical composition is subjected to hot rolling including rough rolling and finish rolling to obtain a hot-rolled steel sheet, and the hot-rolled steel sheet is optionally subjected to hot-rolled sheet annealing and then the hot-rolled steel sheet after the hot rolling or after the hot-rolled sheet annealing is subjected to cold rolling once, or twice or more with intermediate annealing being performed therebetween, to obtain a cold-rolled steel sheet having a final thickness. The cold-rolled steel sheet after the cold rolling is coiled to obtain a cold-rolled coil by a known method. As a result of the vibration being applied to the cold-rolled coil under the foregoing conditions, the diffusible hydrogen content in the steel can be reduced and a cold-rolled steel sheet excellent in hydrogen embrittlement resistance can be obtained. In addition to applying vibration to the cold-rolled coil, the hot-rolled steel sheet after the hot rolling may be coiled to obtain a hot-rolled coil and vibration may be applied to the hot-rolled coil under the foregoing conditions. The hot-rolled coil after the vibration application is then uncoiled to feed the hot-rolled steel sheet, the hot-rolled steel sheet is subjected to cold rolling to obtain a cold-rolled coil, and vibration is applied to the cold-rolled coil. Thus, the diffusible hydrogen content in the steel can be further reduced, and a steel sheet particularly excellent in hydrogen embrittlement resistance can be obtained.

[0054] In this embodiment, the type of the hot-rolled steel sheet or the cold-rolled steel sheet to which vibration is to be applied is not limited. Although the chemical composition of the steel sheet is not limited, for example, a steel sheet having the following chemical composition is particularly suitable for the application of the embodiment. The appropriate range of the chemical composition of the steel sheet and the reasons for limiting the chemical composition to such range will be described below.

[Essential components]

C: 0.030 % or more and 0.800 % or less

[0055] C is an element necessary for increasing the strength. If the C content is 0.030 % or more, particularly suitable strength can be obtained. If the C content is 0.800 % or less, embrittlement of the material itself can be prevented particularly suitably. In view of this, the C content is preferably 0.030 % or more. The C content is preferably 0.800 % or less. The C content is more preferably 0.080 % or more. The C content is more preferably 0.500 % or less.

Si: 0.01 % or more and 3.00 % or less

[0056] Si is a solid-solution-strengthening element that forms a substitutional solid solution and greatly hardens the material, and is effective in increasing the strength of the steel sheet. To achieve the strength increasing effect by the addition of Si, the Si content is preferably 0.01 % or more. From the viewpoint of preventing embrittlement and a ductility decrease of the steel and further preventing red scale and the like to obtain favorable surface characteristics and achieve favorable coating appearance and coating adhesion, the Si content is preferably 3.00 % or less. Therefore, the Si content is preferably 0.01 % or more. The Si content is preferably 3.00 % or less. The Si content is more preferably 0.10 % or more. The Si content is more preferably 2.50 % or less.

Mn: 0.01 % or more and 10.00 % or less

[0057] Mn increases the strength of the steel sheet by solid solution strengthening. To achieve this effect, the Mn content is preferably 0.01 % or more. If the Mn content is 10.00 % or less, the segregation of Mn can be appropriately prevented to prevent the steel microstructure from being nonuniform, thus further suppressing hydrogen embrittlement. Therefore, the Mn content is 10.00 % or less. The Mn content is more preferably 0.5 % or more. The Mn content is more preferably 8.00 % or less.

P: 0.001 % or more and 0.100 % or less

[0058] P is an element that has a solid solution strengthening action and can be added depending on the desired strength. To achieve this effect, the P content is preferably 0.001 % or more. If the P content is 0.100 % or less, excellent weldability can be achieved. If the P content is 0.100 % or less, in the case of forming a galvanized coating or plating on the steel sheet surface and subjecting the galvanized coating or plating to an alloying treatment to form a galvannealed coating, a galvanized coating or plating of excellent quality can be formed without a decrease in alloying rate. Therefore, the P content is preferably 0.001 % or more. The P content is preferably 0.100 % or less. The P content is more preferably 0.003 % or more. The P content is more preferably 0.050 % or less.

S: 0.0001 % or more and 0.0200 % or less

[0059] By reducing the S content, it is possible to appropriately prevent the embrittlement of the steel in hot working and appropriately prevent the formation of sulfide to improve the local deformability. The S content is therefore preferably 0.0200 % or less, more preferably 0.0100 % or less, and further preferably 0.0050 % or less. No lower limit is placed on the S content, but the S content is preferably 0.0001 % or more under manufacturing constraints.

N: 0.0005 % or more and 0.0100 % or less

[0060] By reducing the N content, it is possible to improve the aging resistance of the steel. The N content is therefore preferably 0.0100 % or less, and more preferably 0.0070 % or less. No lower limit is placed on the N content, but the N content is preferably 0.0005 % or more and more preferably 0.0010 % or more under manufacturing constraints.

Al: 2.000 % or less

[0061] Al is an element that acts as a deoxidizer and is effective for the cleanliness of the steel, and is preferably added in a deoxidation step. In the case of adding Al, to achieve the effect of adding Al, the Al content is preferably 0.001 % or more. From the viewpoint of appropriately preventing slab cracking in continuous casting, the Al content is preferably 2.000 % or less. The Al content is more preferably 0.010 % or more. The Al content is more preferably 1.200 % or less.

[Optional components]

[0062] The chemical composition may further contain, in mass%, at least one element selected from the group consisting of Ti: 0.200 % or less, Nb: 0.200 % or less, V: 0.500 % or less, W: 0.500 % or less, B: 0.0050 % or less, Ni: 1.000 % or less, Cr: 1.000 % or less, Mo: 1.000 % or less, Cu: 1.000 % or less, Sn: 0.200 % or less, Sb: 0.200 % or less, Ta: 0.100 % or less, Ca: 0.0050 % or less, Mg: 0.0050 % or less, Zr: 0.0050 % or less, and REM: 0.0050 % or less.

Ti: 0.200 % or less

[0063] Ti contributes to higher strength of the steel sheet by strengthening the steel by precipitation or by grain refinement strengthening through growth inhibition of ferrite crystal grains. In the case of adding Ti, the Ti content is preferably 0.005 % or more. In the case of adding Ti, the Ti content is more preferably 0.010 % or more. If the Ti content is 0.200 % or less, precipitation of carbonitride can be appropriately prevented and the formability can be further improved. Accordingly, in the case of adding Ti, the Ti content is preferably 0.200 % or less. The Ti content is more preferably 0.100 % or less.

Nb: 0.200 % or less, V: 0.500 % or less, W: 0.500 % or less

[0064] Nb, V, and W are effective in strengthening the steel by precipitation. Accordingly, in the case of adding any of Nb, V, and W, the content of each element is preferably 0.005 % or more. In the case of adding any of Nb, V, and W, the content of each element is more preferably 0.010 % or more. If the Nb content is 0.200 % or less or if the content of each of V and W is 0.500 % or less, precipitation of carbonitride can be appropriately prevented and the formability can be further improved, as with Ti. Accordingly, in the case of adding Nb, the Nb content is preferably 0.200 % or less, and more preferably 0.100 % or less. In the case of adding any of V and W, the content of each of V and W is preferably 0.500 % or less, and more preferably 0.300 % or less.

B: 0.0050 % or less

[0065] B is effective in strengthening grain boundaries and strengthening the steel sheet. In the case of adding B, the B content is preferably 0.0003 % or more. To achieve better formability, the B content is preferably 0.0050 % or less. Accordingly, in the case of adding B, the B content is preferably 0.0050 % or less, and more preferably 0.0030 % or less.

Ni: 1.000 % or less

[0066] Ni is an element that increases the strength of the steel by solid solution strengthening. In the case of adding Ni, the Ni content is preferably 0.005 % or more. From the viewpoint of reducing the area ratio of hard martensite and further improving the ductility, the Ni content is preferably 1.000 % or less. Accordingly, in the case of adding Ni, the Ni content is preferably 1.000 % or less, and more preferably 0.500 % or less.

Cr: 1.000 % or less, Mo: 1.000 % or less

[0067] Cr and Mo have an action of improving the balance between the strength and the formability, and may be optionally added. In the case of adding any of Cr and Mo, the content of each element is preferably 0.005 % or more. From the viewpoint of reducing the area ratio of hard martensite and further improving the ductility, the content of each element is preferably 1.000 % or less. The content of each element is more preferably 0.500 % or less.

Cu: 1.000 % or less

[0068] Cu is an element effective in strengthening the steel, and may be optionally added. In the case of adding Cu, the Cu content is preferably 0.005 % or more. In the case of adding Cu, the Cu content is preferably 1.000 % or less and more preferably 0.200 % or less, from the viewpoint of reducing the area ratio of hard martensite and further improving the ductility.

Sn: 0.200 % or less, Sb: 0.200 % or less

[0069] Sn and Sb suppress decarburization of regions of about several tens of μm of the steel sheet surface layer caused by nitridization or oxidation of the steel sheet surface, and thus are effective in ensuring the strength and the material stability when optionally added. In the case of adding any of Sn and Sb, the content of each element is preferably 0.002 % or more. In the case of adding any of Sn and Sb, the content of each element is preferably 0.200 % or less and more preferably 0.050 % or less, in order to further improve the toughness.

Ta: 0.100 % or less

[0070] Ta forms alloy carbide and alloy carbonitride and contributes to higher strength, as with Ti and Nb. Ta is also considered to have an effect of, by partially dissolving in Nb carbide and Nb carbonitride and forming composite precipitate such as (Nb, Ta)(C, N), significantly suppressing the coarsening of precipitate and stabilizing the contribution of precipitation to higher strength. It is thus preferable to add Ta. In the case of adding Ta, the Ta content is preferably 0.001 % or more. Although no upper limit is placed on the Ta content, in the case of adding Ta, the Ta content is preferably 0.100 % or less and more preferably 0.050 % or less, from the viewpoint of cost reduction.

Ca: 0.0050 % or less, Mg: 0.0050 % or less, Zr: 0.0050 % or less, REM: 0.0050 % or less

[0071] Ca, Mg, Zr, and REM are elements effective for spheroidizing sulfide and improving the adverse effect of the sulfide on the formability. In the case of adding any of these elements, the content of each element is preferably 0.0005 % or more. In the case of adding any of these elements, the content of each element is preferably 0.0050 % or less and more preferably 0.0020 % or less in order to appropriately prevent inclusions and the like from increasing and more appropriately prevent surface and internal defects, etc.

[0072] This embodiment can also be suitably applied to high strength steel sheets for which hydrogen embrittlement is particularly problematic. By applying vibration to the steel sheet coil C composed of a high strength steel sheet by the dehydrogenation apparatus 300a or the steel sheet production method, the diffusible hydrogen content in the steel can be reduced and a high strength steel sheet excellent in hydrogen embrittlement resistance can be obtained. For example, the steel sheet produced in this embodiment may be a high strength steel sheet whose tensile strength is 590 MPa or more, more preferably 1180 MPa or more, and further preferably 1470 MPa or more. The tensile strength of the steel sheet is measured in accordance with JIS Z 2241 (2011). In high strength steel sheets, delayed fractures due to hydrogen embrittlement are often problematic. According to this embodiment, a high strength steel sheet excellent in hydrogen embrittlement resistance can be produced without impairing the tensile strength.

[0073] With the dehydrogenation apparatus and the steel sheet production method according to this embodiment, it is also possible to produce stainless steel excellent in hydrogen embrittlement resistance by applying vibration to known stainless steel. The chemical composition in the case where the steel sheet is a stainless steel sheet and the reasons for limiting the chemical composition to such range will be described below.

[Essential components]

C: 0.001 %or more and 0.400 % or less

[0074] C is an element essential for achieving high strength in the stainless steel. If the C content is more than 0.400 %, however, C combines with Cr and precipitates as carbide during tempering in steel production, and the carbide causes degradation in the corrosion resistance and toughness of the steel. If the C content is less than 0.001 %, sufficient strength cannot be obtained. If the C content is more than 0.400 %, the degradation is significant. The C content is therefore 0.001 % or more and 0.400 % or less. The C content is preferably 0.005 % or more. The C content is preferably 0.350 % or less.

Si: 0.01 % or more and 2.00 % or less

[0075] Si is an element useful as a deoxidizer. This effect is achieved if the Si content is 0.01 % or more. If the Si content is excessively high, Si dissolved in the steel decreases the workability of the steel. The upper limit of the Si content is therefore 2.00 %. The Si content is preferably 0.05 % or more. The Si content is preferably 1.8 % or less.

Mn: 0.01 % or more and 5.00 % or less

[0076] Mn has an effect of increasing the strength of the steel. This effect is achieved if the Mn content is 0.01 % or more. If the Mn content is more than 5.00 %, the workability of the steel decreases. The upper limit of the Mn content is therefore 5.00 % or less. The Mn content is preferably 0.05 % or more. The Mn content is preferably 4.6 % or less.

P: 0.001 % or more and 0.100 % or less

[0077] P is an element that promotes grain boundary fractures due to grain boundary segregation. Accordingly, the P content is desirably low. The upper limit of the P content is 0.100 %. The P content is preferably 0.030 % or less, and further preferably 0.020 % or less. Although no lower limit is placed on the P content, the P content is 0.001 % or more under manufacturing constraints.

S: 0.0001 % or more and 0.0200 % or less

[0078] S is an element that exists as a sulfide-based inclusion such as MnS and causes decreases in ductility, corrosion resistance, and the like. These adverse effects are particularly noticeable in the case where the S content is more than 0.0200 %. Accordingly, the S content is desirably as low as possible, and the upper limit of the S content is 0.0200 %. The S content is preferably 0.010 % or less, and further preferably 0.005 % or less. Although no lower limit is placed on the S content, the S content is 0.0001 % or more under manufacturing constraints.

Cr: 9.0 % or more and 28.0 % or less

[0079] Cr is a basic element constituting stainless steel, and is an important element that develops the corrosion resistance. Considering the corrosion resistance in a harsh environment of 180 °C or more, if the Cr content is less than 9.0 %, the corrosion resistance is insufficient, and if the Cr content is more than 28.0 %, the effect is saturated and the economic efficiency is poor. The Cr content is therefore 9.0 % or more and 28.0 % or less. The Cr content is preferably 10.0 % or more. The Cr content is preferably 25.0 % or less.

Ni: 0.01 % or more and 40.0 % or less

[0080] Ni is an element that improves the corrosion resistance of the stainless steel. If the Ni content is less than 0.01 %, the effect is insufficient. If the Ni content is excessively high, the stainless steel hardens and the formability degrades, and stress corrosion cracking tends to occur. The Ni content is therefore 0.01 % or more and 40.0 % or less. The Ni content is preferably 0.1 % or more. The Ni content is preferably 30.0 % or less.

N: 0.0005 % or more and 0.500 % or less

[0081] N is an element detrimental to improving the corrosion resistance of the stainless steel, but is also an austenite forming element. If the N content is more than 0.5 %, N precipitates as nitride during heat treatment, causing degradation in the corrosion resistance and toughness of the stainless steel. The upper limit of the N content is therefore 0.500 %, and preferably 0.20 %.

Al: 3.000 % or less

[0082] Al is added as a deoxidizing element, and also has an effect of suppressing exfoliation of oxide scale. If the Al content is more than 3.000 %, the elongation decreases and the surface quality degrades. The upper limit of the Al content is therefore 3.000 %. Although no lower limit is placed on the Al content, the Al content is preferably 0.001 % or more, and more preferably 0.01 % or more. The Al content is preferably 2.5 % or less.

[Optional components]

[0083] The chemical composition of the stainless steel may further contain, in mass%, at least one element selected from the group consisting of Ti: 0.500 % or less, Nb: 0.500 % or less, V: 0.500 % or less, W: 2.000 % or less, B: 0.0050 % or less, Mo: 2.000 % or less, Cu: 3.000 % or less, Sn: 0.500 % or less, Sb: 0.200 % or less, Ta: 0.100 % or less, Ca: 0.0050 % or less, Mg: 0.0050 % or less, Zr: 0.0050 % or less, and REM: 0.0050 % or less.

Ti: 0.500 % or less

[0084] Ti is an element added to combine with C, N, and S and improve the corrosion resistance, the intergranular corrosion resistance, and the deep drawability. If the Ti content is more than 0.500 %, solute Ti hardens the stainless steel and degrades the toughness. The upper limit of the Ti content is therefore 0.500 %. Although no lower limit is placed on the Ti content, the Ti content is preferably 0.003 % or more, and more preferably 0.005 % or more. The Ti content is preferably 0.300 % or less.

Nb: 0.500 % or less

[0085] Nb is an element added to combine with C, N, and S and improve the corrosion resistance, the intergranular corrosion resistance, and the deep drawability, as with Ti. Nb also improves the workability and the high-temperature strength, and suppresses crevice corrosion and facilitates repassivation. Hence, Nb is optionally added. If the Nb content is excessively high, the stainless steel hardens and the formability degrades. The upper limit of the Nb content is therefore 0.500 %. Although no lower limit is placed on the Nb content, the Nb content is preferably 0.003 % or more, and more preferably 0.005 % or more. The Nb content is preferably 0.300 % or less.

V: 0.500 % or less

[0086] V suppresses crevice corrosion, and accordingly is optionally added. If the V content is excessively high, the stainless steel hardens and the formability degrades. The upper limit of the V content is therefore 0.500 %. Although no lower limit is placed on the V content, the V content is preferably 0.01 % or more, and more preferably 0.03 % or more. The V content is preferably 0.300 % or less.

W: 2.000 % or less

[0087] W contributes to improved corrosion resistance and high-temperature strength, and accordingly is optionally added. If the W content is more than 2.000 %, the stainless steel hardens and the toughness degrades in steel sheet production, and the costs increase. The upper limit of the W content is therefore 2.000 %. Although no lower limit is placed on the W content, the W content is preferably 0.050 % or more, and more preferably 0.010 % or more. The W content is preferably 1.500 % or less.

B: 0.0050 % or less

[0088] B is an element that segregates to grain boundaries to improve the secondary workability of the product. B is optionally added to prevent longitudinal cracking when performing secondary working on parts and also prevent cracking in winter. If the B content is excessively high, the workability and the corrosion resistance decrease. The upper limit of the B content is therefore 0.0050 %. Although no lower limit is placed on the B content, the B content is preferably 0.0002 % or more, and more preferably 0.0005 % or more. The B content is preferably 0.0035 % or less.

Mo: 2.000 % or less

[0089] Mo is an element that improves the corrosion resistance and, in the case where the steel sheet has a crevice structure, suppresses crevice corrosion. If the Mo content is more than 2.0 %, the formability degrades significantly. The upper limit of the Mo content is therefore 2.000 %. Although no lower limit is placed on the Mo content, the Mo content is preferably 0.005 % or more, and more preferably 0.010 % or more. The Mo content is preferably 1.500 % or less.

Cu: 3.000 % or less

[0090] Cu is an austenite stabilizing element as with Ni and Mn, and is effective in crystal grain refinement by phase transformation. Cu also suppresses crevice corrosion and facilitates repassivation. Hence, Cu is optionally added. If the Cu content is excessively high, the stainless steel hardens and the toughness and the formability degrade. The upper limit of the Cu content is therefore 3.000 %. Although no lower limit is placed on the Cu content, the Cu content is preferably 0.005 % or more, and more preferably 0.010 % or more. The Cu content is preferably 2.000 % or less.

Sn: 0.500 % or less

[0091] Sn contributes to improved corrosion resistance and high-temperature strength, and accordingly is optionally added. If the Sn content is more than 0.500 %, slab cracking may occur in steel sheet production. The Sn content is therefore 0.500 % or less. Although no lower limit is placed on the Sn content, the Sn content is preferably 0.002 % or more, and more preferably 0.005 % or more. The Sn content is preferably 0.300 % or less.

Sb: 0.200 % or less

[0092] Sb is an element that has an action of segregating to grain boundaries and increasing the high-temperature strength. If the Sb content is more than 0.200 %, the segregation of Sb occurs, which causes cracking in welding. The upper limit of the Sb content is therefore 0.200 %. Although no lower limit is placed on the Sb content, the Sb content is preferably 0.002 % or more, and more preferably 0.005 % or more. The Sb content is preferably 0.100 % or less.

Ta: 0.100 % or less

[0093] Ta combines with C and N and contributes to improved toughness, and accordingly is optionally added. If the Ta content is more than 0.100 %, the effect is saturated, and the production costs increase. The upper limit of the Ta content is therefore 0.100 %. Although no lower limit is placed on the Ta content, the Ta content is preferably 0.002 % or more, and more preferably 0.005 % or more. The Ta content is preferably 0.080 % or less.

Ca: 0.0050 % or less, Mg: 0.0050 % or less, Zr: 0.0050 % or less, REM (rare earth metal): 0.0050 % or less

[0094] Ca, Mg, Zr, and REM are elements effective for spheroidizing sulfide and improving the adverse effect of the sulfide on the formability. In the case of adding any of these elements, the content of each element is preferably 0.0005 % or more. If the content of each element is excessively high, inclusions and the like increase, as a result of which surface and internal defects may occur. Accordingly, in the case of adding any of these elements, the content of each element is 0.0050 % or less. Although no lower limit is placed on the content of each element, the content of each element is preferably 0.0002 % or more, and more preferably 0.0005 % or more. The content of each element is preferably 0.0035 % or less.

[[Annealing line]]

[[Annealing step]]

[0095] The foregoing cold-rolled steel sheet or hot-rolled steel sheet may be subjected to annealing. That is, the steel sheet production system may comprise an annealing line configured to anneal the cold-rolled steel sheet or hot-rolled steel sheet. The annealing timing is not limited. However, given that usually hydrogen enters into steel in an annealing step, the annealing is preferably performed before the vibration application in order to finally obtain a steel sheet excellent in hydrogen embrittlement resistance. The annealing line may be a batch annealing furnace or a continuous annealing line.

[Batch annealing]

[0096] In the case of performing the annealing step using a batch annealing furnace, the steel sheet production system comprises: a batch annealing furnace configured to subject a cold-rolled coil or a hot-rolled coil to batch annealing to obtain an annealed coil; and the dehydrogenation apparatus 300a configured to use the annealed coil as the steel sheet coil C. The batch annealing furnace subjects the cold-rolled coil or the hot-rolled coil to batch annealing to obtain an annealed coil. Herein, "batch annealing" denotes heating and holding in a batch annealing furnace, and does not include slow cooling after the heating and holding. The annealed coil after the annealing is cooled by furnace cooling in the batch annealing furnace, air cooling, or the like. The dehydrogenation apparatus 300a applies vibration to the annealed coil as the steel sheet coil C under the foregoing conditions. The dehydrogenation apparatus 300a may be provided separately from the batch annealing furnace. Alternatively, the housing 80 and the heater of the dehydrogenation apparatus 300a may also serve as the batch annealing furnace. In other words, the vibration application device 60 that applies vibration to the steel sheet coil C housed in the batch annealing furnace to obtain a product coil may be provided in the batch annealing furnace, as the dehydrogenation apparatus 300a. In the case where the housing 80 and the heater of the dehydrogenation apparatus 300a also serve as the batch annealing furnace, the vibration application may be performed after cooling the annealed coil to room temperature or while cooling the annealed coil, after the batch annealing. Diffusible hydrogen can be reduced more efficiently when the temperature of the steel sheet is higher, as mentioned above. Hence, although the vibration application may be performed after cooling the annealed coil to room temperature after the batch annealing, diffusible hydrogen in the steel can be reduced more efficiently by performing the vibration application while cooling the annealed coil after the batch annealing.

[0097] In the case of performing the annealing step using the batch annealing furnace, the steel sheet production method comprises a step of subjecting a cold-rolled coil or a hot-rolled coil obtained by coiling a cold-rolled steel sheet or a hot-rolled steel sheet to batch annealing to obtain an annealed coil, wherein vibration is applied to the annealed coil as the steel sheet coil under the foregoing conditions. First, a cold-rolled steel sheet or a hot-rolled steel sheet is coiled to obtain a cold-rolled coil or a hot-rolled coil by a known method. Following this, the cold-rolled coil or the hot-rolled coil is placed in the batch annealing furnace, and subjected to batch annealing in the batch annealing furnace to obtain an annealed coil. The annealed coil after the annealing is cooled by furnace cooling in the batch annealing furnace, air cooling, or the like. Vibration is then applied to the annealed coil under the foregoing conditions. The application of vibration to the annealed coil may be performed during the batch annealing, i.e. while heating and holding the cold-rolled coil or the hot-rolled coil. The vibration application may be performed after the batch annealing, i.e. after heating and holding the cold-rolled coil or the hot-rolled coil. The vibration application may be performed after cooling the annealed coil to room temperature or while cooling the annealed coil, after the batch annealing. Diffusible hydrogen can be reduced more efficiently when the temperature of the steel sheet is higher, as mentioned above. Hence, it is preferable to perform the vibration application during the batch annealing, or perform the vibration application on the annealed coil while cooling the annealed coil after the batch annealing. The application of vibration to the annealed coil may be performed in the batch annealing furnace, or performed after taking out the annealed coil from the batch annealing furnace. Preferably, vibration is applied to the annealed coil in the batch annealing furnace. As a result of the vibration being applied to the annealed coil in the batch annealing furnace, diffusible hydrogen in the steel can be reduced efficiently.

[Annealing by continuous annealing line]

[0098] Annealing may be performed by passing a cold-rolled steel sheet or a hot-rolled steel sheet through a continuous annealing line (CAL). In the case of performing the annealing step using the continuous annealing line, the steel sheet production system comprises: a pre-annealing uncoiler configured to uncoil a cold-rolled coil or a hot-rolled coil to feed a cold-rolled steel sheet or a hot-rolled steel sheet, respectively; a continuous annealing furnace configured to subject the cold-rolled steel sheet or the hot-rolled steel sheet to continuous annealing to obtain an annealed steel sheet; an annealed steel sheet coiler configured to coil the annealed steel sheet to obtain an annealed coil; and the dehydrogenation apparatus 300a configured to use the annealed coil as the steel sheet coil C. The pre-annealing uncoiler uncoils a cold-rolled coil or a hot-rolled coil to feed a cold-rolled steel sheet or a hot-rolled steel sheet respectively, and supplies the cold-rolled steel sheet or the hot-rolled steel sheet to the CAL. The structure of the CAL is not limited. In one example, the CAL includes a continuous annealing furnace in which a heating zone, a soaking zone, and a cooling zone are arranged in this order. The cooling zone may be composed of a plurality of cooling zones. In such a case, the plurality of cooling zones may include a holding zone in which the cold-rolled steel strip in the cooling process is held in a certain temperature range and/or a reheating zone in which the steel sheet in the cooling process is reheated. A preheating zone may be provided upstream of the heating zone in the sheet passing direction. The pre-annealing uncoiler may be a payoff reel located upstream of the continuous annealing furnace in the CAL. The annealed steel sheet coiler may be a tension reel located downstream of the continuous annealing furnace in the CAL. In the CAL, (A) the cold-rolled coil or the hot-rolled coil is uncoiled to feed the cold-rolled steel sheet or the hot-rolled steel sheet respectively by the payoff reel, (B) the cold-rolled steel sheet or the hot-rolled steel sheet is passed through the continuous annealing furnace in which the heating zone, the soaking zone, and the cooling zone are arranged from the upstream side in the sheet passing direction to continuously anneal the cold-rolled steel sheet or the hot-rolled steel sheet by (B-1) annealing the cold-rolled steel sheet or the hot-rolled steel sheet to obtain an annealed steel sheet in the heating zone and the soaking zone and (B-2) cooling the annealed steel sheet in the cooling zone, (C) the annealed steel sheet discharged from the continuous annealing furnace is continuously passed, and (D) the steel sheet is coiled by the tension reel to obtain an annealed coil. The dehydrogenation apparatus 300a applies vibration to the annealed coil as the steel sheet coil C under the foregoing conditions. As a result of the vibration application, the diffusible hydrogen content in the steel can be reduced and an annealed steel sheet excellent in hydrogen embrittlement resistance can be obtained. The cooling method and the cooling rate of the steel sheet in the cooling zone are not limited, and any cooling such as gas jet cooling, mist cooling, or water cooling may be used.

[0099] In the case of performing the annealing step using a continuous annealing line, the steel sheet production method comprises: a step of uncoiling a cold-rolled coil to feed a cold-rolled steel sheet; a step of continuously annealing the cold-rolled steel sheet to obtain an annealed steel sheet; and a step of coiling the annealed steel sheet to obtain an annealed coil, wherein the annealed coil is the steel sheet coil. In the CAL, (A) the steel sheet coil is uncoiled by the payoff reel, (B) the steel sheet is passed through the annealing furnace in which the heating zone, the soaking zone, and the cooling zone are arranged from the upstream side in the sheet passing direction to continuously anneal the steel sheet by (B-1) annealing the steel sheet in the heating zone and the soaking zone and (B-2) cooling the steel sheet in the cooling zone, (C) the steel sheet discharged from the annealing furnace is continuously passed, and (D) the steel sheet is coiled by the tension reel to obtain an annealed coil. As a result of the vibration being applied to the annealed coil being under the foregoing conditions, a cold-rolled steel sheet or a hot-rolled steel sheet excellent in hydrogen embrittlement resistance can be obtained.

[[Coated or plated steel sheet]]

[0100] The dehydrogenation apparatus 300a according to this embodiment can also be applied to the production of coated or plated steel sheets. A steel sheet production system according to this application example comprises: a coating or plating apparatus configured to form a coating or plating on a surface of a hot-rolled steel sheet or a cold-rolled steel sheet to obtain a coated or plated steel sheet; a coated or plated steel sheet coiler configured to coil the coated or plated steel sheet to obtain a coated or plated steel sheet coil; and the dehydrogenation apparatus 300a configured to use the coated or plated steel sheet coil as the steel sheet coil C. The coating or plating apparatus forms a coating or plating on the surface of a hot-rolled steel sheet or a cold-rolled steel sheet as a base steel sheet to obtain a coated or plated steel sheet. The coated or plated steel sheet coiler coils the coated or plated steel sheet to obtain a coated or plated steel sheet coil. The dehydrogenation apparatus 300a applies vibration to the coated or plated steel sheet coil as the steel sheet coil C under the foregoing conditions. As a result of the vibration application, the diffusible hydrogen content in the steel can be reduced and a coated or plated steel sheet excellent in hydrogen embrittlement resistance can be obtained.

[0101] A coating or plating may be formed on the surface of a hot-rolled steel sheet or a cold-rolled steel sheet as a base steel sheet to obtain a coated or plated steel sheet, which is then used as a steel sheet coil to which vibration is to be applied. In the case of applying vibration to a coated or plated steel sheet coil, the steel sheet production method comprises: a step of forming a coating or plating on a surface of a hot-rolled steel sheet or a cold-rolled steel sheet to obtain a coated or plated steel sheet; and a step of coiling the coated or plated steel sheet to obtain a coated or plated steel sheet coil, wherein the coated or plated steel sheet coil is the steel sheet coil.

[Formation of coating or plating by continuous hot-dip galvanizing line]

[0102] The type of the coating or plating apparatus is not limited. For example, the coating or plating apparatus may be a hot-dip galvanizing apparatus. In one example, the hot-dip galvanizing apparatus may be a continuous hot-dip galvanizing line (CGL). The structure of the CGL is not limited. In one example, the CGL includes: a continuous annealing furnace in which a heating zone, a soaking zone, and a cooling zone are arranged in this order; and a hot-dip galvanizing apparatus located downstream of the cooling zone. In the CGL, (A) the cold-rolled coil or the hot-rolled coil is uncoiled to feed the cold-rolled steel sheet or the hot-rolled steel sheet respectively by the payoff reel, (B) the cold-rolled steel sheet or the hot-rolled steel sheet is passed through the continuous annealing furnace in which the heating zone, the soaking zone, and the cooling zone are arranged from the upstream side in the sheet passing direction to continuously anneal the cold-rolled steel sheet or the hot-rolled steel sheet by (B-1) annealing the hot-rolled steel sheet or the cold-rolled steel sheet in a reducing atmosphere containing hydrogen to obtain an annealed steel sheet in the soaking zone and (B-2) cooling the annealed steel sheet in the cooling zone, (C) the annealed steel sheet discharged from the annealing furnace is continuously passed to (C-1) immerse the annealed steel sheet in a hot-dip galvanizing bath located downstream of the continuous annealing furnace in the sheet passing direction to subject the annealed steel sheet to a hot-dip galvanizing treatment and obtain a hot-dip galvanized steel sheet, and (D) the hot-dip galvanized steel sheet is coiled by the tension reel to obtain a hot-dip galvanized steel sheet coil. The dehydrogenation apparatus 300a applies vibration to the hot-dip galvanized steel sheet coil as the steel sheet coil C under the foregoing conditions. As a result of the vibration application, the diffusible hydrogen content in the steel can be reduced and a hot-dip galvanized steel sheet excellent in hydrogen embrittlement resistance can be obtained.

[0103] The method of forming the coating or plating on the surface of the hot-rolled steel sheet or the cold-rolled steel sheet is not limited, and the coating or plating step may include a hot-dip galvanizing step. That is, the hot-rolled steel sheet or the cold-rolled steel sheet may be subjected to a hot-dip galvanizing treatment to obtain a hot-dip galvanized steel sheet. In one example, the steel sheet may be subjected to a hot-dip galvanizing treatment using a continuous hot-dip galvanizing line (CGL). In the CGL, (A) the steel sheet coil is uncoiled by the payoff reel, (B) the hot-rolled steel sheet or the cold-rolled steel sheet is passed through the annealing furnace in which the heating zone, the soaking zone, and the cooling zone are arranged from the upstream side in the sheet passing direction to continuously anneal the hot-rolled steel sheet or the cold-rolled steel sheet by (B-1) annealing the hot-rolled steel sheet or the cold-rolled steel sheet in a reducing atmosphere containing hydrogen to obtain an annealed steel sheet in the soaking zone and (B-2) cooling the annealed steel sheet in the cooling zone, (C) the annealed steel sheet discharged from the annealing furnace is continuously passed, and (D) the annealed steel sheet is coiled by the tension reel to obtain an annealed coil. The step (C) includes (C-1) immersing the annealed steel sheet in a hot-dip galvanizing bath located downstream of the annealing furnace in the sheet passing direction to subject the annealed steel sheet to a hot-dip galvanizing treatment. The annealed coil obtained by the coiling is a hot-dip galvanized steel sheet coil composed of a hot-dip galvanized steel sheet. As a result of the vibration being applied to the hot-dip galvanized steel sheet coil under the foregoing conditions, a hot-dip galvanized steel sheet excellent in hydrogen embrittlement resistance can be obtained.

[0104] The coating or plating apparatus may include a hot-dip galvanizing apparatus and an alloying furnace following the hot-dip galvanizing apparatus. In one example, after producing a hot-dip galvanized steel sheet using the CGL, i.e. after the foregoing step (C-1), (C-2) the steel sheet is passed through the alloying furnace located downstream of the hot-dip galvanizing bath in the sheet passing direction to heat and alloy the hot-dip galvanizing. A galvannealed steel sheet obtained by alloying in the alloying furnace is coiled into a galvannealed steel sheet coil. The dehydrogenation apparatus 300a applies vibration to the galvannealed steel sheet coil as the steel sheet coil C under the foregoing conditions. As a result of the vibration application, a galvannealed steel sheet excellent in hydrogen embrittlement resistance can be obtained.

[0105] The coating or plating step may include a hot-dip galvanizing step and an alloying step following the hot-dip galvanizing step. That is, the hot-dip galvanized steel sheet may be further subjected to an alloying treatment to obtain a galvannealed steel sheet, and then vibration may be applied to the galvannealed steel sheet. In one example, after producing a hot-dip galvanized steel sheet using the CGL, i.e. after the foregoing step (C-1), (C-2) the steel sheet is passed through the alloying furnace located downstream of the hot-dip galvanizing bath in the sheet passing direction to heat and alloy the hot-dip galvanizing. A galvannealed steel sheet obtained by alloying in the alloying furnace is coiled into a galvannealed steel sheet coil. As a result of the vibration being applied to the galvannealed steel sheet coil under the foregoing conditions, a galvannealed steel sheet excellent in hydrogen embrittlement resistance can be obtained.

[0106] The coating or plating apparatus is not limited to forming a galvanized coating or plating, and may form an Al coating or plating or a Fe coating or plating. The coating or plating apparatus is not limited to a hot-dip coating apparatus, and may be an electroplating apparatus.

[0107] The type of the coating or plating that can be formed on the surface of the steel sheet to which vibration is to be applied is not limited, and may be an Al coating or plating or a Fe coating or plating. The method of forming the coating or plating is not limited to a hot-dip coating step, and may be an electroplating step.

[0108] The steel sheet production system may further comprise a skin pass rolling mill configured to subject the above-obtained hot-rolled steel sheet, cold-rolled steel sheet, or coated or plated steel sheet having any of various coatings or platings on the hot-rolled steel sheet or cold-rolled steel sheet to skin pass rolling for the purpose of shape adjustment, surface roughness adjustment, etc. That is, the steel sheet production method may subject the above-obtained hot-rolled steel sheet, cold-rolled steel sheet, or coated or plated steel sheet having any of various coatings or platings on the hot-rolled steel sheet or cold-rolled steel sheet to skin pass rolling for the purpose of shape adjustment, surface roughness adjustment, etc. The rolling reduction ratio of the skin pass rolling is preferably controlled to be 0.1 % or more, and preferably controlled to be 2.0 % or less. If the rolling reduction ratio of the skin pass rolling is 0.1 % or more, the effect of shape adjustment and the effect of surface roughness adjustment can be enhanced, and the rolling reduction ratio can be easily controlled. If the rolling reduction ratio of the skin pass rolling is 2.0 % or less, the productivity can be improved. The skin pass rolling mill may be continuous with the CGL or CAL (inline), or not continuous with the CGL or CAL (offline). Skin pass rolling of the target rolling reduction ratio may be performed at one time, or skin pass rolling may be performed several times to achieve the target rolling reduction ratio. The steel sheet production system may further comprise a coating apparatus configured to apply any of various coating treatments such as resin or oil coating to the surface of the above-obtained hot-rolled steel sheet, cold-rolled steel sheet, or coated or plated steel sheet having any of various coatings or platings on the hot-rolled steel sheet or cold-rolled steel sheet. That is, any of various coating treatments such as resin or oil coating may be applied to the surface of the above-obtained hot-rolled steel sheet, cold-rolled steel sheet, or coated or plated steel sheet having any of various coatings or platings on the hot-rolled steel sheet or cold-rolled steel sheet.

<Embodiment 2>

[0109] A dehydrogenation apparatus according to Embodiment 2 of the present disclosure comprises: an uncoiler configured to uncoil a steel sheet coil to feed a steel strip; a sheet passing device configured to pass the steel strip therethrough; a coiler configured to coil the steel strip; and a vibration application device configured to apply vibration to the steel strip being passed through the sheet passing device so that the steel strip is caused to vibrate at a frequency of 100 Hz to 100,000 Hz and a maximum amplitude of 10 nm to 500 μm.

[0110] A steel sheet production method according to Embodiment 2 of the present disclosure comprises: a step of uncoiling a steel sheet coil to feed a steel strip; a sheet passing step of passing the steel strip; and a step of coiling the steel strip to obtain a product coil, wherein the sheet passing step includes a vibration application step of applying vibration to the steel strip so that the steel strip is caused to vibrate at a frequency of 100 Hz to 100,000 Hz and a maximum amplitude of 10 nm to 500 μm.

[0111] A steel sheet optionally subjected to annealing after hot rolling or cold rolling or a coated or plated steel sheet obtained by further forming a coating or plating on the steel sheet is coiled into a steel sheet coil. Since the mass of the steel sheet coil is often different from the packaging mass at the time of shipment, division by the packaging mass is performed in the recoiling line. The uncoiler uncoils the steel sheet coil to feed the steel strip, and the recoiler recoils the steel strip fed. Once the recoiled steel strip has reached a predetermined packaging mass, the steel strip is sheared and divided. In this embodiment, vibration is applied to the steel strip uncoiled by this recoiling line. According to this embodiment, vibration is applied to the steel strip being passed, so that the steel strip can be uniformly applied with vibration throughout its length. The dehydrogenation apparatus according to this embodiment is an apparatus not continuous with the continuous annealing line or the continuous hot-dip galvanizing line (offline), and the dehydrogenation apparatus does not include a line for performing annealing, a coating or plating treatment, and a hot-dip galvanizing treatment on the steel strip.

(Vibration application device 60)

[0112] A vibration application device can be used for application of vibration. For example, the vibration application device may be configured to cause the steel strip being passed to vibrate in response to an external force (attractive force) exerted by an electromagnet 63 on the steel strip, as described above in relation to the vibration application device 60 according to Embodiment 1. The vibration application device 60 may be configured similarly to that in Embodiment 1, except that the object to which vibration is applied is not a steel sheet coil but a steel strip being passed.

[0113] It is suffice for the electromagnets 63 to be installed to face one surface of the steel strip being passed, yet the electromagnets 63 may be installed so as to face both the front and back surfaces of the steel strip. However, in such cases, it is preferable to shift the height positions of the electromagnets 63 so that the electromagnets on one side are not at the same height position as the electromagnets on the other side.

(Vibration application device 70)

[0114] In another example, the vibration application device can be configured to cause the steel strip being passed to vibrate in response to an external force (attractive force) exerted by a vibration element exerted on the steel strip, as described above in relation to the vibration application device 70 according to Embodiment 1. As illustrated in FIG. 4A, the vibration application device 70 may comprise a vibration element 72 configured to contact the steel strip S being passed, and the vibration application device 70 may be configured to cause the steel strip to be vibrated by the vibration element 72. The vibration application device 70 may be configured similarly to that of Embodiment 1, except that the object to which vibration is applied is not a steel sheet coil but a steel strip being passed.

[[Dehydrogenation apparatus]]

[0115] FIG. 7 is a view of a dehydrogenation apparatus 300b used in the steel sheet production method according to this embodiment, as seen in the transverse direction of a steel strip S. FIG. 7 is a view illustrating an example of a dehydrogenation apparatus for reducing diffusible hydrogen in the steel by applying vibration to a steel strip S being passed using the vibration application device 60. In the dehydrogenation apparatus 300b, vibration application devices

60 are arranged in the passage of the steel strip S fed as a result of uncoiling by the uncoiler, as illustrated in FIG. 7. Although not illustrated, in each vibration application device 60, each electromagnet 63 is coupled with an amplifier 62, a power supply 65, and a controller 61, which controller is further coupled with a vibration detector 64, so that vibration is applied from the electromagnet 63 to the steel strip S. The vibration application devices 60 may be provided only on one of the front and back sides of the steel strip S being passed, or provided on both of the front and back sides of the steel strip S being passed to vibrate the steel strip S, as illustrated in FIG. 7. By providing the vibration application devices 60 on both of the front and back sides of the steel strip S being passed, the vibration application timing can be controlled to reduce the diffusible hydrogen content in the steel more efficiently. The dehydrogenation apparatus 300b includes a sheet passing device (not illustrated) that passes the steel strip S from the uncoiler toward the coiler. The sheet passing device includes, for example, a sheet passing roll for passing the steel strip S toward the coiler.

[0116] A plurality of electromagnets 63 are preferably arranged in the steel strip transverse direction, with certain spacing from the surface of the steel strip S being passed. By applying vibration to the surface of the steel strip S being passed from each electromagnet 63, the surface can be uniformly applied with the vibration in the transverse direction. By arranging, in the sheet passing direction, a plurality of electromagnet groups each of which is made up of a plurality of electromagnets 63 arranged in the steel strip transverse direction, the surface of the steel strip S can be exposed to vibration for sufficient time.

[0117] The configuration for holding the electromagnets 63 at regular intervals in the dehydrogenation apparatus 300b is not limited. For example, a box-shaped portion may be provided on the sheet path (i.e. the path through which the steel strip S is passed) so as to cover the steel strip S being passed, and the electromagnets 63 may be fixed to the inner wall of the box-shaped portion at regular intervals.

[0118] FIG. 8 illustrates an example of a dehydrogenation apparatus for reducing diffusible hydrogen in the steel by applying vibration to a steel strip S being passed using the vibration application device 70. In FIG. 8, the width direction of the steel strip S is shown in the foreground. In the dehydrogenation apparatus 300b, vibration elements 72 of the vibration application device 70 are arranged in the passage of the steel strip S fed as a result of uncoiling by the uncoiler, as illustrated in FIG. 8. In each vibration application device 70, each vibration element 72 is coupled with a controller 61 and a vibration detector 73 so that vibration is applied from the vibration element 72 to the steel strip S. As illustrated in FIG. 8, each vibration element 72 is arranged so as to contact the steel strip S being passed. The vibration application devices 70 may be provided only on one of the front and back sides of the steel strip S being passed, or provided on both of the front and back sides of the steel strip S being passed to vibrate the steel strip S. By providing the vibration application devices 70 on both of the front and back sides of the steel strip S being passed, the vibration application timing can be controlled to reduce the diffusible hydrogen content in the steel more efficiently.

[0119] It is preferable that a plurality of vibration elements 72 be provided along the steel strip transverse direction so that the vibration elements 72 are in contact with the surface of the steel strip S being passed. By applying vibration to the surface of the steel strip S being passed from each vibration element 72, the surface can be uniformly applied with the vibration in the transverse direction. By arranging, in the sheet passing direction, a plurality of vibration element groups each of which is made up of a plurality of vibration elements 72 arranged in the steel strip transverse direction, the surface of the steel strip S can be exposed to vibration for sufficient time.

[0120] The configuration for holding the vibration elements 72 at regular intervals in the dehydrogenation apparatus 300b is not limited. For example, a box-shaped portion may be provided on the sheet path (i.e. the path through which the steel strip S is passed) so as to cover the steel strip S being passed, and the vibration elements 72 may be fixed to the inner wall of the box-shaped portion at regular intervals.

[0121] In this embodiment, the frequency and the maximum amplitude of the vibration applied to the steel strip being passed may be the same as in Embodiment 1.

[[Vibration application time]]

[0122] In the recoiling line, there is no need to adjust the sheet passing rate in view of the annealing time, unlike in the continuous annealing line or the continuous hot-dip galvanizing line. Hence, according to this embodiment, vibration can be applied to the steel strip without any constraint on the irradiation time. Since a longer vibration application time is expected to contribute to reduction of more diffusible hydrogen, the vibration application time is preferably 1 minute or more. The vibration application time is more preferably 30 minutes or more, and further preferably 60 minutes or more. From the viewpoint of productivity, the vibration application time is preferably 30,000 minutes or less, more preferably 10,000 minutes or less, and further preferably 1,000 minutes or less. The vibration application time can be adjusted based on the sheet passing rate of the steel strip S and the position of the vibration application device (for example, the number of vibration application device groups arranged in the sheet passing direction where each group is made up of a plurality of vibration application devices 60 arranged in the steel sheet transverse direction).

[0123] According to this embodiment, the diffusible hydrogen content in the product coil obtained after the vibration application can be reduced to 0.5 mass ppm or less. As a result of the diffusible hydrogen content in the product coil being reduced to 0.5 mass ppm or less, hydrogen embrittlement can be prevented. The diffusible hydrogen content in the steel after the vibration application is preferably 0.3 mass ppm or less, and further preferably 0.2 mass ppm or less. The diffusible hydrogen content in the steel after the vibration application can be measured in the same way as in Embodiment 1.

[[Heater]]

[[Holding temperature of steel strip]]

[0124] As illustrated in FIGS. 7 and 8, the dehydrogenation apparatus 300b may further comprise a heater 74 configured to heat the steel strip S at 300 °C or less while vibration is applied to the steel strip S. The temperature of the steel strip S in the vibration application step is not limited. According to this embodiment, diffusible hydrogen in the steel can be reduced even without heating and holding the steel strip S. By applying vibration to the steel strip S while heating the steel strip S by a heater, however, the hydrogen diffusion rate can be further increased, as a result of which the diffusible hydrogen content in the steel can be further reduced. Accordingly, the temperature of the steel strip S when applying vibration is preferably 30 °C or more, more preferably 50 °C or more, and further preferably 100 °C or more. No upper limit is placed on the temperature of the steel strip S in the vibration application step, but the temperature of the steel strip S in the vibration application step is preferably 300 °C or less from the viewpoint of appropriately preventing the microstructural changes of the steel strip S. In this embodiment, the temperature of the steel strip S when applying vibration is based on the temperature of the surface of the steel strip S. The surface temperature of the steel strip can be measured by a typical radiation thermometer. The arrangement of the heater 74 is not limited. For example, the heater 74 may be provided on the sheet path of the steel strip S, as illustrated in FIGS. 7 and 8. By providing the heater 74 on the sheet path of the steel strip S, the steel strip S can be uniformly heated. In the case of providing the heater 74 on the sheet path of the steel strip S, the heater 74 is preferably located upstream of the vibration application devices 60 in the sheet path, as illustrated in FIGS. 7 and 8. As a result of the heater 74 being located upstream of the vibration application devices 60 in the sheet path, vibration can be applied to the sufficiently heated steel strip S. For example, vibration can be applied to the steel strip S while being heated and held by a method of covering the steel sheet being passed with the aforementioned box-shaped portion and installing a heater on the side wall of the box-shaped portion. Moreover, vibration can be applied to the steel strip S while being heated and held by a method of blowing high-temperature air generated outside to the box-shaped portion and circulating it in the box-shaped portion. The heating method is not limited, and may be any of combustion heating and electric heating. In one example, the heater 74 may be an induction heater.

[0125] The dehydrogenation apparatus 300b according to this embodiment may further comprise a vibration damper configured to prevent the vibration from being transmitted to the outside of the dehydrogenation apparatus 300b. The specific structure of the vibration damper is not limited. However, the vibration damper may be, for example, a vibration damping material provided to surround the steel strip S and the electromagnets 63.

[0126] Application examples of this embodiment will be described in detail below.

[[Hot-rolled steel sheet]]

[0127] The dehydrogenation apparatus 300b and the steel sheet production method according to this embodiment can be applied to the production of hot-rolled steel sheets, as in Embodiment 1.

[0128] A steel sheet production system according to this application example comprises: a hot rolling mill configured to subject a steel slab to hot rolling to obtain a hot-rolled steel sheet; a hot-rolled steel sheet coiler configured to coil the hot-rolled steel sheet to obtain a hot-rolled coil; and the dehydrogenation apparatus 300b configured to use the hot-rolled coil as the steel sheet coil. A hot-rolled coil produced by a known hot rolling mill is uncoiled to feed a hot-rolled steel sheet, the hot-rolled steel sheet is passed, and vibration is applied to the hot-rolled steel sheet being passed under the foregoing conditions. As a result, the diffusible hydrogen content in the steel can be reduced and a hot-rolled steel sheet excellent in hydrogen embrittlement resistance can be obtained.

[0129] The steel sheet production method according to this embodiment can be applied to the production of hot-rolled steel sheets, as in Embodiment 1. A steel sheet production method according to this application example comprises: a step of subjecting a steel slab to hot rolling to obtain a hot-rolled steel sheet; and a step of coiling the hot-rolled steel sheet to obtain a hot-rolled coil, wherein the hot-rolled coil is the steel sheet coil. The hot-rolled coil production method before vibration application is not limited, and may be, for example, the production method described in Embodiment 1. The hot-rolled coil is uncoiled to feed a hot-rolled steel sheet, the hot-rolled steel sheet is passed, and vibration is applied to the hot-rolled steel sheet being passed under the foregoing conditions. As a result, the diffusible hydrogen content in the steel can be reduced and a hot-rolled steel sheet excellent in hydrogen embrittlement resistance can be obtained.

[[Cold-rolled steel sheet]]

[0130] The dehydrogenation apparatus 300b and the steel sheet production method according to this embodiment can also be applied to the production of cold-rolled steel sheets.

[0131] A steel sheet production system according to this application example comprises: a cold rolling mill configured to subject a hot-rolled steel sheet to cold rolling to obtain a cold-rolled steel sheet; a cold-rolled steel sheet coiler configured to coil the cold-rolled steel sheet to obtain a cold-rolled coil; and the dehydrogenation apparatus 300b configured to use the cold-rolled coil as the steel sheet coil C. A known cold rolling mill subjects a known hot-rolled steel sheet to cold rolling to obtain a cold-rolled steel sheet. The cold-rolled steel sheet coiler coils the cold-rolled steel sheet to obtain a cold-rolled coil. The cold-rolled coil as the steel sheet coil C is uncoiled to feed a cold-rolled steel sheet, the cold-rolled steel sheet is passed, and vibration is applied to the cold-rolled steel sheet being passed under the foregoing conditions. As a result, the diffusible hydrogen content in the steel can be reduced and a cold-rolled steel sheet excellent in hydrogen embrittlement resistance can be obtained.

[0132] A steel sheet production method according to this application example comprises: a step of subjecting a hot-rolled steel sheet to cold rolling to obtain a cold-rolled steel sheet; and a step of coiling the cold-rolled steel sheet to obtain a cold-rolled coil, wherein the cold-rolled coil is the steel sheet coil. The cold-rolled coil production method before vibration application is not limited, and may be, for example, the production method described in Embodiment 1. The cold-rolled coil is uncoiled to feed a cold-rolled steel sheet, the cold-rolled steel sheet is passed, and vibration is applied to the cold-rolled steel sheet being passed under the foregoing conditions. As a result, the diffusible hydrogen content in the steel can be reduced and a cold-rolled steel sheet excellent in hydrogen embrittlement resistance can be obtained.

[0133] The chemical composition of each of the hot-rolled steel sheet and the cold-rolled steel sheet to which vibration is to be applied by the dehydrogenation apparatus 300b is not limited. However, according to this embodiment, by applying vibration to a high strength steel sheet whose tensile strength is 590 MPa or more, more preferably 1180 MPa or more, and further preferably 1470 MPa or more by the dehydrogenation apparatus 300b, the diffusible hydrogen content in the steel can be reduced and a high strength steel sheet excellent in hydrogen embrittlement resistance can be obtained.

[0134] The chemical composition of each of the hot-rolled steel sheet and the cold-rolled steel sheet may be, for example, the chemical composition described in Embodiment 1.

[[Annealing line]]

[0135] The steel sheet production system may comprise an annealing line configured to anneal the cold-rolled steel sheet or the hot-rolled steel sheet, as in Embodiment 1. The annealing timing is not limited. However, given that usually hydrogen enters into steel in an annealing step, the annealing is preferably performed before the vibration application in order to finally obtain a steel sheet excellent in hydrogen embrittlement resistance. The annealing line may be a batch annealing furnace or a continuous annealing line.

[[Annealing step]]

[0136] The cold-rolled steel sheet or the hot-rolled steel sheet may be subjected to annealing, as in Embodiment 1. The annealing timing is not limited, but the annealing is preferably performed before the vibration application step. The annealing step may be performed using a batch annealing furnace or a continuous annealing line.

[Batch annealing]

[0137] In the case of performing the annealing step using a batch annealing furnace, the steel sheet production system comprises: a batch annealing furnace configured to subject a cold-rolled coil or a hot-rolled coil to batch annealing to obtain an annealed coil; and the dehydrogenation apparatus 300b configured to use the annealed coil as the steel sheet coil C. The annealed coil after the annealing is cooled by furnace cooling in the batch annealing furnace, air cooling, or the like. The uncoiler uncoils the annealed coil to feed an annealed steel sheet to the sheet passing device, and the sheet passing device passes the annealed steel sheet. The vibration application device 60 applies vibration to the annealed steel sheet being passed under the foregoing conditions. As a result of the vibration application, the diffusible hydrogen content in the steel can be reduced and an annealed steel sheet excellent in hydrogen embrittlement resistance can be obtained.

[0138] In the case of performing the annealing step using the batch annealing furnace, the steel sheet production method comprises: a step of coiling a cold-rolled steel sheet or a hot-rolled steel sheet to obtain a cold-rolled coil or a hot-rolled coil; and a step of subjecting the cold-rolled coil or the hot-rolled coil to batch annealing to obtain an annealed coil, wherein the annealed coil is the steel sheet coil. The annealed coil after the annealing is cooled by furnace cooling in the batch annealing furnace, air cooling, or the like. Following this, the annealed coil is uncoiled to feed an annealed steel sheet, the annealed steel sheet is passed, and vibration is applied to the annealed steel sheet being passed under the foregoing conditions. As a result, the diffusible hydrogen content in the steel can be reduced and an annealed steel sheet excellent in hydrogen embrittlement resistance can be obtained.

[Annealing by continuous annealing line]

[0139] Annealing may be performed by passing a cold-rolled steel sheet or a hot-rolled steel sheet through a continuous annealing line (CAL). In the case of performing the annealing step using the continuous annealing line, the steel sheet production system comprises: a pre-annealing uncoiler configured to uncoil a cold-rolled coil or a hot-rolled coil to feed a cold-rolled steel sheet or a hot-rolled steel sheet, respectively; a continuous annealing furnace configured to subject the cold-rolled steel sheet or the hot-rolled steel sheet to continuous annealing to obtain an annealed steel sheet; an annealed steel sheet coiler configured to coil the annealed steel sheet to obtain an annealed coil; and the dehydrogenation apparatus 300b configured to use the annealed coil as the steel sheet coil C. The structure of the continuous annealing line is the same as that in Embodiment 1. In the dehydrogenation apparatus 300b, the uncoiler uncoils the annealed coil to feed an annealed steel sheet to the sheet passing device, and the sheet passing device passes the annealed steel sheet. The vibration application device 60 applies vibration to the annealed steel sheet being passed under the foregoing conditions. As a result of the vibration application, the diffusible hydrogen content in the steel can be reduced and an annealed steel sheet excellent in hydrogen embrittlement resistance can be obtained.

[0140] In the case of performing the annealing step using the continuous annealing line, the annealed coil before the vibration application can be produced in the same way as in Embodiment 1. The annealed coil is uncoiled to feed the annealed steel strip and vibration is applied to the annealed steel sheet being passed under the foregoing conditions. As a result, an annealed steel sheet excellent in hydrogen embrittlement resistance can be obtained.

[[Coated or plated steel sheet]]

[0141] The dehydrogenation apparatus 300b and the steel sheet production method according to this embodiment can also be applied to the production of coated or plated steel sheets, as in Embodiment 1.

[0142] A steel sheet production system according to this application example comprises: a coating or plating apparatus configured to form a coating or plating on a surface of a hot-rolled steel sheet or a cold-rolled steel sheet to obtain a coated or plated steel sheet; a coated or plated steel sheet coiler configured to coil the coated or plated steel sheet to obtain a coated or plated steel sheet coil; and the dehydrogenation apparatus 300b configured to use the coated or plated steel sheet coil as the steel sheet coil C. The type of the coating or plating that can be formed on the surface of the hot-rolled steel sheet or the cold-rolled steel sheet is not limited, and may be a galvanized coating or plating, an Al coating or plating, or a Fe coating or plating. The coating or plating method is not limited to a hot-dip coating step, and may be an electroplating step.

[0143] A steel sheet production method according to this application example comprises: a step of forming a coating or plating on a surface of a hot-rolled steel sheet or a cold-rolled steel sheet to obtain a coated or plated steel sheet; and a step of coiling the coated or plated steel sheet to obtain a coated or plated steel sheet coil, wherein the coated or plated steel sheet coil is the steel sheet coil.

[Formation of coating or plating by continuous hot-dip galvanizing line]

[0144] The type of the coating or plating apparatus is not limited. For example, the coating or plating apparatus may be a hot-dip galvanizing apparatus. In one example, the hot-dip galvanizing apparatus may be a continuous hot-dip galvanizing line (CGL). The structure of the CGL may be the same as that in Embodiment 1. In the dehydrogenation apparatus 300b, the uncoiler uncoils the hot-dip galvanized steel sheet coil produced by the CGL to feed a hot-dip galvanized steel sheet to the sheet passing device, and the sheet passing device passes the hot-dip galvanized steel sheet. The vibration application device 60 applies vibration to the annealed steel sheet being passed under the foregoing conditions. As a result of the vibration application, the diffusible hydrogen content in the steel can be reduced and a hot-dip galvanized steel sheet excellent in hydrogen embrittlement resistance can be obtained.

[0145] The steel sheet before the vibration application may be subjected to a hot-dip galvanizing treatment to obtain a hot-dip galvanized steel sheet. In one example, the steel strip may be subjected to a hot-dip galvanizing treatment using a continuous hot-dip galvanizing line (CGL). The structure of the CGL may be the same as that in Embodiment 1. The hot-dip galvanized steel sheet coil before the vibration application can be produced in the same way as in Embodiment 1. The hot-dip galvanized steel sheet coil is uncoiled to feed the hot-dip galvanized steel sheet, the hot-dip galvanized steel sheet is passed, and vibration is applied to the hot-dip galvanized steel sheet being passed under the foregoing conditions. As a result, a hot-dip galvanized steel sheet excellent in hydrogen embrittlement resistance can be obtained.

[0146] The coating or plating apparatus may include a hot-dip galvanizing apparatus and an alloying furnace following the hot-dip galvanizing apparatus. That is, in the steel sheet production method, the coating or plating step may include a hot-dip galvanizing step and an alloying step following the hot-dip galvanizing step. As the coating or plating apparatus including the alloying furnace, for example, the CGL including the alloying furnace downstream of the hot-dip galvanizing bath in the sheet passing direction in Embodiment 1 may be used. The galvannealed steel sheet coil produced by the hot-dip galvanizing step and the alloying step following the hot-dip galvanizing step is uncoiled to feed the galvannealed steel sheet, and vibration is applied to the galvannealed steel sheet under the foregoing conditions. As a result, a galvannealed steel sheet excellent in hydrogen embrittlement resistance can be obtained.

[0147] The steel sheet production system may further comprise a skin pass rolling mill that subjects the above-obtained hot-rolled steel sheet, cold-rolled steel sheet, or coated or plated steel sheet having any of various coatings or platings on the hot-rolled steel sheet or cold-rolled steel sheet to skin pass rolling for the purpose of shape adjustment, surface roughness adjustment, etc., as in Embodiment 1. The steel sheet production system may further comprise a coating apparatus that applies any of various coating treatments such as resin or oil coating to the surface of the above-obtained hot-rolled steel sheet, cold-rolled steel sheet, or coated or plated steel sheet having any of various coatings or platings on the hot-rolled steel sheet or cold-rolled steel sheet.

[0148] That is, the steel sheet production method may subject the above-obtained hot-rolled steel sheet, cold-rolled steel sheet, or coated or plated steel sheet having any of various coatings or platings on the hot-rolled steel sheet or cold-rolled steel sheet to skin pass rolling, as in Embodiment 1. Moreover, any of various coating treatments such as resin or oil coating may be applied to the surface of the above-obtained hot-rolled steel sheet, cold-rolled steel sheet, or coated or plated steel sheet having any of various coatings or platings on the hot-rolled steel sheet or cold-rolled steel sheet.

EXAMPLES

<First Example>

[0149] Steel materials each having a chemical composition listed in Table 1 with the balance being Fe and inevitable impurities were each obtained by steelmaking using a converter, and continuously cast into a steel slab. The obtained steel slab was subjected to hot rolling, followed by cold rolling and subsequent annealing to obtain a cold-rolled steel sheet (CR). Some of the cold-rolled steel sheets were further subjected to hot-dip galvanizing to obtain a hot-dip galvanized steel sheet (GI). Some of the hot-dip galvanized steel sheets were further subjected to alloying treatment to obtain galvannealed steel sheets (GA). The CR, the GI, and the GA were each 1.4 mm in thickness and 1,000 mm in width. As the CAL, a CAL in which a heating zone, a soaking zone, and a cooling zone are arranged in this order was used. As the CGL, a CGL including: a continuous annealing furnace in which a heating zone, a soaking zone, and a cooling zone are arranged in this order; and a hot-dip galvanizing apparatus located downstream of the cooling zone was used. As the batch annealing furnace, a typical batch annealing furnace was used.

[Table 1]

Table 1

Steel sample ID	Chemical composition (mass%)																						Remarks
	C	Si	Mn	P	S	N	Al	Ti	Nb	V	W	B	Ni	Cr	Mo	Cu	Sn	Sb	Ta	Ca	Mg	Zr	REM	
A	0.211	1.02	2.91	0.007	0.0015	0.0041	0.029	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Disclosed steel
B	0.153	1.45	3.06	0.012	0.0016	0.0036	0.032	0.031	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Disclosed steel
C	0.413	0.51	2.75	0.006	0.0012	0.0042	0.025	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Disclosed steel
D	0.195	0.84	2.95	0.009	0.0011	0.0036	0.037	0.021	-	-	-	0.0012	-	-	-	-	-	-	-	-	-	-	-	Disclosed steel
E	0.187	0.51	2.65	0.007	0.0009	0.0037	0.031	-	-	-	-	-	-	-	0.12	-	-	-	-	-	-	-	-	Disclosed steel
F	0.209	0.35	3.21	0.009	0.0008	0.0042	0.035	-	0.012	-	0.05	-	-	-	-	-	-	-	-	0.0032	0.0025	0.0034	0.0021	Disclosed steel
G	0.231	1.12	2.97	0.008	0.0013	0.0039	0.028	-	0.021	-	-	0.0010	-	-	-	-	-	0.010	-	-	-	-	-	Disclosed steel
H	0.216	0.95	3.02	0.011	0.0012	0.0036	0.039	-	-	0.05	-	-	-	0.21	-	-	-	-	0.008	-	-	-	-	Disclosed steel
I	0.179	0.71	3.14	0.007	0.0010	0.0041	0.034	-	-	-	-	-	0.10	-	-	0.15	0.006	-	-	-	-	-	-	Disclosed steel

Underlined if outside the scope of the disclosure. - indicates an inevitable impurity level content.

[0150] Vibration was applied to the obtained steel sheet coil of each of the CR, the GI, and the GA or a steel strip fed as a result of uncoiling the steel sheet coil. The vibration application was performed using the vibration application device illustrated in FIG. 1 or 4, under the conditions of the frequency, the maximum amplitude, and the irradiation time listed in Table 2. In Table 2, A denotes the case of applying vibration to a steel sheet coil, and B denotes the case of applying vibration to a fed steel strip. In the case of applying vibration to a steel sheet coil, the dehydrogenation apparatus illustrated in FIGS. 5A, 5C, and 6 was used. In the case of applying vibration to a steel strip, the dehydrogenation apparatus illustrated in FIGS. 3 and 4A was used. In the case of applying vibration to a steel sheet coil (outer diameter: 1,500 mm, inner diameter: 610 mm, width: 1,000 mm), the size of the housing was 2,500 mm in height, 2,000 mm in depth, and 2,500 mm in width. In the case of applying vibration to a steel sheet coil by electromagnets, the electromagnets were arranged on the inner wall of the housing so as to surround the steel sheet coil. In the case of applying vibration to a steel sheet coil by vibration elements, vibration elements 72 were arranged on the surface of the steel sheet coil along its circumferential direction with a spacing of 10° from each other at the center angle thereof. In the case of applying vibration to a steel strip being passed, the electromagnets or vibration elements were arranged on both of the front and back sides of the steel strip being passed. Six electromagnets were arranged evenly in the steel strip transverse direction from a steel strip transverse edge. In Table 2, "room temperature" refers to approximately 25 °C. The maximum amplitude was adjusted by adjusting the frequency and current value of the current to flow through the electromagnets or the frequency and current value of the pulsed direct current to flow through the vibration elements, while fixing the position of the vibration application device (i.e. the distance between the vibration application device and the steel strip S or steel sheet coil C). In the case of applying vibration to a steel sheet coil, the vibration application time was adjusted by adjusting the drive time of the vibration application device. In the case of applying vibration to a fed steel strip, the vibration application time was adjusted by adjusting the sheet passing rate of the steel strip.

[0151] For each steel sheet after the vibration application, the tensile property, the diffusible hydrogen content in steel, the stretch flangeability, and the bendability were evaluated by the following methods. The results are listed in Table 2.

[0152] A tensile test was conducted in accordance with JIS Z 2241 (2011). A JIS No. 5 test piece was collected from each steel sheet after the vibration application so that the tensile direction would be perpendicular to the rolling direction of the steel sheet. Using the test piece, the tensile test was conducted under the conditions of a crosshead displacement rate of 1.67×10^{-1} mm/s, and TS (tensile strength) was measured.

[0153] The stretch flangeability was evaluated by a hole expanding test. The hole expanding test was conducted in accordance with JIS Z 2256. A sample of 100 mm $\times$ 100 mm was collected from the obtained steel sheet by shearing. A hole with a diameter of 10 mm was drilled through the sample with clearance 12.5 %. In a state in which the periphery of the hole was clamped using a die having an inner diameter of 75 mm with a blank holding force of 9 tons (88.26 kN), a conical punch with an apical angle of 60° was pushed into the hole, and the hole diameter at crack initiation limit was measured. The maximum hole expansion ratio λ (%) was calculated using the following equation (4), and the hole expansion formability was evaluated from the maximum hole expansion ratio.

$$\text{Maximum hole expansion ratio: } \lambda\ (\%) = \{(D_f - D_0)/D_0\} \times 100 \quad \ldots (4)$$

where D_f is the hole diameter at the time of occurrence of cracking (mm), and D_0 is the initial hole diameter (mm). In the case where the value of λ was 20 % or more, the stretch flangeability was determined as favorable regardless of the strength of the steel sheet.

[0154] A bend test was conducted in accordance with JIS Z 2248. A strip test piece of 30 mm in width and 100 mm in length was collected from the obtained steel sheet so that the axial direction of the bend test would be parallel to the rolling direction of the steel sheet. The bend test was then conducted by a V-block bend test with a bending angle of 90°, under the conditions of an indentation load of 100 kN and a pressing-holding time of 5 seconds. In the present disclosure, a 90° V bend test was conducted, the ridge line part of the bending apex was observed with a microscope (RH-2000 produced by HIROX Co., Ltd.) with 40 magnification, and the bending radius when cracks of 200 μm or more in crack length were no longer observed was taken to be the minimum bending radius (R). In the case where the value (R/t) obtained by dividing R by the thickness (t) was 5.0 or less, the result of the bend test was determined as favorable.

[0155] The diffusible hydrogen content in steel was measured by the foregoing method.

[0156] As can be understood from Table 2, in each Example, the vibration application step was performed, so that a steel sheet having low hydrogen content and excellent in stretch flangeability (λ) and bendability (R/t) as indexes of hydrogen embrittlement resistance was able to be produced. In each Comparative Example, on the other hand, one or both of the stretch flangeability (λ) and the bendability (R/t) was poor.

[Table 2]

[0157]

Table 2

No.	Steel sample ID	Steel sheet production line	Dehydrogenation apparatus						Steel sheet					Remarks
			Steel strip condition1)	Vibration application device (electromagnetic or direct vibration)	Maximum amplitude (nm)	Frequency (Hz)	Vibration application time (s)	Vibration application temp. (°C)	Type2)	Amount of hydrogen in steel sheet (mass ppm)	TS (MPa)	λ (%)	R/t	
1	A	continuous annealing	A	electromagnetic vibration	5000	1000	30	room temperature	CR	0.32	1521	39	2.7	Example
2	B	continuous annealing	A	electromagnetic vibration	8000	1000	3600	room temperature	CR	0.10	1367	47	1.9	Example
3	C	continuous annealing	B	direct vibration	10000	1000	180	room temperature	CR	0.17	1791	37	2.5	Example
4	D	continuous annealing	A	electromagnetic vibration	15000	1200	1800	100°C	CR	0.12	1512	40	1.9	Example
5	D	continuous annealing	-	-	-	-	-	-	CR	0.55	1488	18	5.3	Comparative example
6	D	continuous hot-dip coating	A	direct vibration	9000	1000	3600	room temperature	GA	0.26	1521	39	3.0	Example
7	D	continuous hot-dip coating	A	electromagnetic vibration	20000	1000	7200	room temperature	GA	0.24	1495	41	2.2	Example
8	D	continuous hot-dip coating	A	electromagnetic vibration	10000	80	1200	room temperature	GA	0.60	1505	14	6.3	Comparative example
9	D	continuous hot-dip coating	A	electromagnetic vibration	12000	1000	3600	room temperature	GA	0.22	1522	41	2.4	Example

(continued)

No.	Steel sample ID	Steel sheet production line	Dehydrogenation apparatus						Steel sheet					Remarks
			Steel strip condition[1)]	Vibration application device (electromagnetic or direct vibration)	Maximum amplitude (nm)	Frequency (Hz)	Vibration application time (s)	Vibration application temp. (°C)	Type[2)]	Amount of hydrogen in steel sheet (mass ppm)	TS (MPa)	λ (%)	R/t	
10	D	continuous hot-dip coating	A	electromagnetic vibration	16000	<u>120000</u>	3600	room temperature	GA	0.58	1512	17	6.2	Comparative example
11	D	continuous hot-dip coating	A	electromagnetic vibration	5	1000	3600	room temperature	GA	<u>0.54</u>	1532	<u>18</u>	<u>7.0</u>	Comparative example
12	D	continuous hot-dip coating	A	electromagnetic vibration	150	1000	3600	room temperature	GA	0.41	1515	25	4.3	Example
13	D	continuous hot-dip coating	A	electromagnetic vibration	280000	1000	3600	room temperature	GA	0.11	1499	43	1.8	Example
14	D	continuous hot-dip coating	A	electromagnetic vibration	<u>600000</u>	1000	3600	room temperature	GA	<u>0.55</u>	1501	<u>15</u>	<u>6.5</u>	Comparative example
15	E	continuous hot-dip coating	A	electromagnetic vibration	15000	1000	3600	room temperature	GI	0.32	1489	40	3.9	Example
16	F	continuous hot-dip coating	A	electromagnetic vibration	100000	1000	3600	100°C	GA	0.11	1527	44	2.0	Example
17	G	continuous hot-dip coating	B	electromagnetic vibration	50000	1000	20	room temperature	GA	0.39	1473	35	4.5	Example

(continued)

No.	Steel sample ID	Steel sheet production line	Dehydrogenation apparatus						Steel sheet					Remarks
			Steel strip condition[1)]	Vibration application device (electromagnetic or direct vibration)	Maximum amplitude (nm)	Frequency (Hz)	Vibration application time (s)	Vibration application temp. (°C)	Type[2)]	Amount of hydrogen in steel sheet (mass ppm)	TS (MPa)	λ (%)	R/t	
18	H	continuous hot-dip coating	B	electromagnetic vibration	30000	1000	180	room temperature	GI	0.43	1519	21	5.1	Example
19	I	continuous hot-dip coating	B	electromagnetic vibration	10000	1000	180	room temperature	GA	0.32	1490	35	4.1	Example
20	D	continuous hot-dip coating	-	-	-	-	-	-	GA	<u>0.75</u>	1472	<u>11</u>	<u>7.9</u>	Comparative example

Underlined if outside the appropriate range of the present disclosure.
1) A: coil condition, B: steel sheet condition
2) CR: cold-rolled steel sheet, GI: hot-dip galvanized steel sheet (without alloying treatment of galvanizing), GA: galvannealed steel sheet

[0158] In each Example, the vibration application was performed on the steel sheet, so that a steel sheet excellent in hydrogen embrittlement resistance was able to be produced.

REFERENCE SIGNS LIST

[0159]

60	vibration application device
61	controller
62	amplifier
63	electromagnet
63A	magnet
63A1	magnetic pole surface
63B	coil
64	vibration detector
65	power supply
70	vibration application device
71	controller
72	vibration element
73	vibration detector
74	heater
80	housing
90	coil holder
300a, 300b	dehydrogenation apparatus
S	steel strip
C	steel sheet coil

Claims

1. A dehydrogenation apparatus comprising:

a housing configured to house a steel sheet coil obtained by coiling a steel strip; and
a vibration application device configured to apply vibration to the steel sheet coil housed in the housing so that the steel sheet coil is caused to vibrate at a frequency of 100 Hz to 100,000 Hz and a maximum amplitude of 10 nm to 500 μm.

2. The dehydrogenation apparatus according to claim 1, wherein the vibration application device comprises an electromagnet having a magnetic pole surface spaced from and facing a surface of the steel sheet coil, and the vibration application device is configured to cause the steel sheet coil to vibrate in response to an external force exerted by the electromagnet on the steel sheet coil.

3. The dehydrogenation apparatus according to claim 1, wherein the vibration application device comprises a vibration element configured to contact the steel sheet coil, and the vibration application device is configured to cause the steel sheet coil to be vibrated by the vibration element.

4. The dehydrogenation apparatus according to any one of claims 1 to 3, further comprising a heater configured to heat the steel sheet coil while the vibration is applied to the steel sheet coil.

5. A dehydrogenation apparatus comprising:

an uncoiler configured to uncoil a steel sheet coil to feed a steel strip;
a sheet passing device configured to pass the steel strip therethrough;
a coiler configured to coil the steel strip; and
a vibration application device configured to apply vibration to the steel strip being passed through the sheet passing device so that the steel strip is caused to vibrate at a frequency of 100 Hz to 100,000 Hz and a maximum amplitude of 10 nm to 500 μm.

6. The dehydrogenation apparatus according to claim 5, wherein the vibration application device comprises an electromagnet having a magnetic pole surface spaced from and facing a surface of the steel strip being passed, and the vibration application device is configured to cause the steel strip to vibrate in response to an external force exerted by the electromagnet on the steel strip.

7. The dehydrogenation apparatus according to claim 5, wherein the vibration application device comprises a vibration element configured to contact the steel strip being passed, and the vibration application device is configured to cause the steel strip to be vibrated by the vibration element.

8. The dehydrogenation apparatus according to any one of claims 5 to 7, further comprising a heater configured to heat the steel strip while the vibration is applied to the steel strip.

9. The dehydrogenation apparatus according to any one of claims 1 to 8, further comprising a vibration damper configured to prevent the vibration from being transmitted to the outside of the dehydrogenation apparatus.

10. A steel sheet production system comprising:

a hot rolling mill configured to subject a steel slab to hot rolling to obtain a hot-rolled steel sheet;
a hot-rolled steel sheet coiler configured to coil the hot-rolled steel sheet to obtain a hot-rolled coil; and
the dehydrogenation apparatus according to any one of claims 1 to 9 configured to use the hot-rolled coil as the steel sheet coil.

11. A steel sheet production system comprising:

a cold rolling mill configured to subject a hot-rolled steel sheet to cold rolling to obtain a cold-rolled steel sheet;
a cold-rolled steel sheet coiler configured to coil the cold-rolled steel sheet to obtain a cold-rolled coil; and
the dehydrogenation apparatus according to any one of claims 1 to 9 configured to use the cold-rolled coil as the steel sheet coil.

12. A steel sheet production system comprising:

a batch annealing furnace configured to subject a cold-rolled coil or a hot-rolled coil to batch annealing to obtain an annealed coil; and
the dehydrogenation apparatus according to any one of claims 1 to 9 configured to use the annealed coil as the steel sheet coil.

13. A steel sheet production system comprising:

a pre-annealing uncoiler configured to uncoil a cold-rolled coil or a hot-rolled coil to feed a cold-rolled steel sheet or a hot-rolled steel sheet, respectively;
a continuous annealing furnace configured to subject the cold-rolled steel sheet or the hot-rolled steel sheet to continuous annealing to obtain an annealed steel sheet;
an annealed steel sheet coiler configured to coil the annealed steel sheet to obtain an annealed coil; and
the dehydrogenation apparatus according to any one of claims 1 to 9 configured to use the annealed coil as the steel sheet coil.

14. A steel sheet production system comprising:

a coating or plating apparatus configured to form a coating or plating on a surface of a hot-rolled steel sheet or a cold-rolled steel sheet to obtain a coated or plated steel sheet;
a coated or plated steel sheet coiler configured to coil the coated or plated steel sheet to obtain a coated or plated steel sheet coil; and
the dehydrogenation apparatus according to any one of claims 1 to 9 configured to use the coated or plated steel sheet coil as the steel sheet coil.

15. The steel sheet production system according to claim 14, wherein the coating or plating apparatus is a hot-dip galvanizing apparatus.

16. The steel sheet production system according to claim 14, wherein the coating or plating apparatus includes: a hot-dip galvanizing apparatus; and an alloying furnace following the hot-dip galvanizing apparatus.

17. The steel sheet production system according to claim 14, wherein the coating or plating apparatus is an electroplating apparatus.

18. A steel sheet production method comprising a vibration application step of applying vibration to a steel sheet coil obtained by coiling a steel strip so that the steel sheet coil is caused to vibrate at a frequency of 100 Hz to 100,000 Hz and a maximum amplitude of 10 nm to 500 μm, to obtain a product coil.

19. The steel sheet production method according to claim 18, wherein the vibration application step is performed while holding the steel sheet coil at 300 °C or less.

20. A steel sheet production method comprising:

a step of uncoiling a steel sheet coil to feed a steel strip;
a sheet passing step of passing the steel strip; and
a step of coiling the steel strip to obtain a product coil,
wherein the sheet passing step includes a vibration application step of applying vibration to the steel strip so that the steel strip is caused to vibrate at a frequency of 100 Hz to 100,000 Hz and a maximum amplitude of 10 nm to 500 μm.

21. The steel sheet production method according to claim 20, wherein the vibration application step is performed while holding the steel strip at 300 °C or less.

22. The steel sheet production method according to any one of claims 18 to 21, comprising:

a step of subjecting a steel slab to hot rolling to obtain a hot-rolled steel sheet; and
a step of coiling the hot-rolled steel sheet to obtain a hot-rolled coil,
wherein the hot-rolled coil is the steel sheet coil.

23. The steel sheet production method according to any one of claims 18 to 21, comprising:

a step of subjecting a hot-rolled steel sheet to cold rolling to obtain a cold-rolled steel sheet; and
a step of coiling the cold-rolled steel sheet to obtain a cold-rolled coil,
wherein the cold-rolled coil is the steel sheet coil.

24. The steel sheet production method according to any one of claims 18 to 21, comprising a step of subjecting a cold-rolled coil or a hot-rolled coil to batch annealing to obtain an annealed coil,
wherein the annealed coil is the steel sheet coil.

25. The steel sheet production method according to any one of claims 18 to 21, comprising:

a step of uncoiling a cold-rolled coil or a hot-rolled coil to feed a cold-rolled steel sheet or a hot-rolled steel sheet, respectively;
a step of subjecting the cold-rolled steel sheet or the hot-rolled steel sheet to continuous annealing to obtain an annealed steel sheet; and
a step of coiling the annealed steel sheet to obtain an annealed coil,
wherein the annealed coil is the steel sheet coil.

26. The steel sheet production method according to any one of claims 18 to 21, comprising:

a coating or plating step of forming a coating or plating on a surface of a hot-rolled steel sheet or a cold-rolled steel sheet to obtain a coated or plated steel sheet; and
a step of coiling the coated or plated steel sheet to obtain a coated or plated steel sheet coil,
wherein the coated or plated steel sheet coil is the steel sheet coil.

27. The steel sheet production method according to claim 26, wherein the coating or plating step includes a hot-dip

galvanizing step.

28. The steel sheet production method according to claim 26, wherein the coating or plating step includes: a hot-dip galvanizing step; and an alloying step following the hot-dip galvanizing step.

29. The steel sheet production method according to claim 26, wherein the coating or plating step includes an electroplating step.

30. The steel sheet production method according to any one of claims 18 to 29, wherein the product coil is composed of a high strength steel sheet having a tensile strength of 590 MPa or more.

31. The steel sheet production method according to any one of claims 18 to 30, wherein the product coil includes a base steel sheet having a chemical composition containing, in mass%,

C: 0.030 % or more and 0.800 % or less,
Si: 0.01 % or more and 3.00 % or less,
Mn: 0.01 % or more and 10.00 % or less,
P: 0.001 % or more and 0.100 % or less,
S: 0.0001 % or more and 0.0200 % or less,
N: 0.0005 % or more and 0.0100 % or less, and
Al: 2.000 % or less,
with the balance being Fe and inevitable impurities.

32. The steel sheet production method according to claim 31, wherein the chemical composition further contains, in mass%, at least one element selected from the group consisting of

Ti: 0.200 % or less,
Nb: 0.200 % or less,
V: 0.500 % or less,
W: 0.500 % or less,
B: 0.0050 % or less,
Ni: 1.000 % or less,
Cr: 1.000 % or less,
Mo: 1.000 % or less,
Cu: 1.000 % or less,
Sn: 0.200 % or less,
Sb: 0.200 % or less,
Ta: 0.100 % or less,
Ca: 0.0050 % or less,
Mg: 0.0050 % or less,
Zr: 0.0050 % or less, and
REM: 0.0050 % or less.

33. The steel sheet production method according to any one of claims 18 to 30, wherein the product coil includes a stainless steel sheet having a chemical composition containing, in mass%,

C: 0.001 % or more and 0.400 % or less,
Si: 0.01 % or more and 2.00 % or less,
Mn: 0.01 % or more and 5.00 % or less,
P: 0.001 % or more and 0.100 % or less,
S: 0.0001 % or more and 0.0200 % or less,
Cr: 9.0 % or more and 28.0 % or less,
Ni: 0.01 % or more and 40.0 % or less,
N: 0.0005 % or more and 0.500 % or less, and
Al: 3.000 % or less,
with the balance being Fe and inevitable impurities.

34. The steel sheet production method according to claim 33, wherein the chemical composition further contains, in mass%, at least one element selected from the group consisting of

Ti: 0.500 % or less,
Nb: 0.500 % or less,
V: 0.500 % or less,
W: 2.000 % or less,
B: 0.0050 % or less,
Mo: 2.000 % or less,
Cu: 3.000 % or less,
Sn: 0.500 % or less,
Sb: 0.200 % or less,
Ta: 0.100 % or less,
Ca: 0.0050 % or less,
Mg: 0.0050 % or less,
Zr: 0.0050 % or less, and
REM: 0.0050 % or less.

35. The steel sheet production method according to any one of claims 18 to 34, wherein the product coil has a diffusible hydrogen content of 0.50 mass ppm or less.

FIG. 1

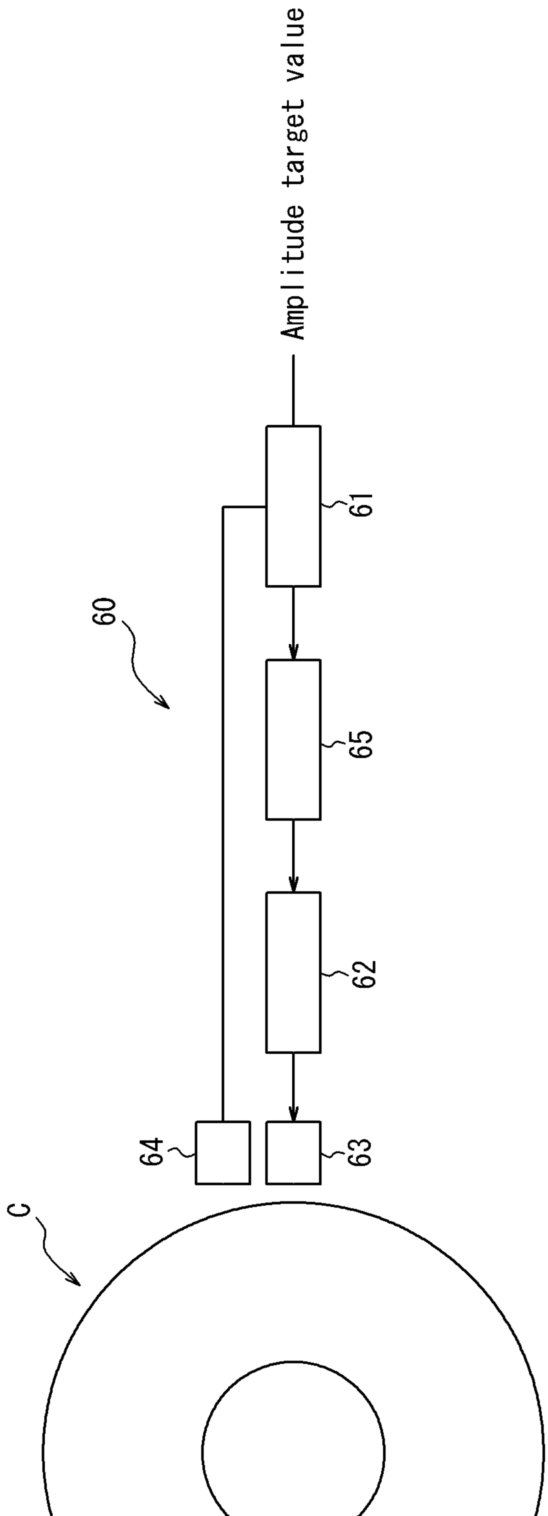


FIG. 2A

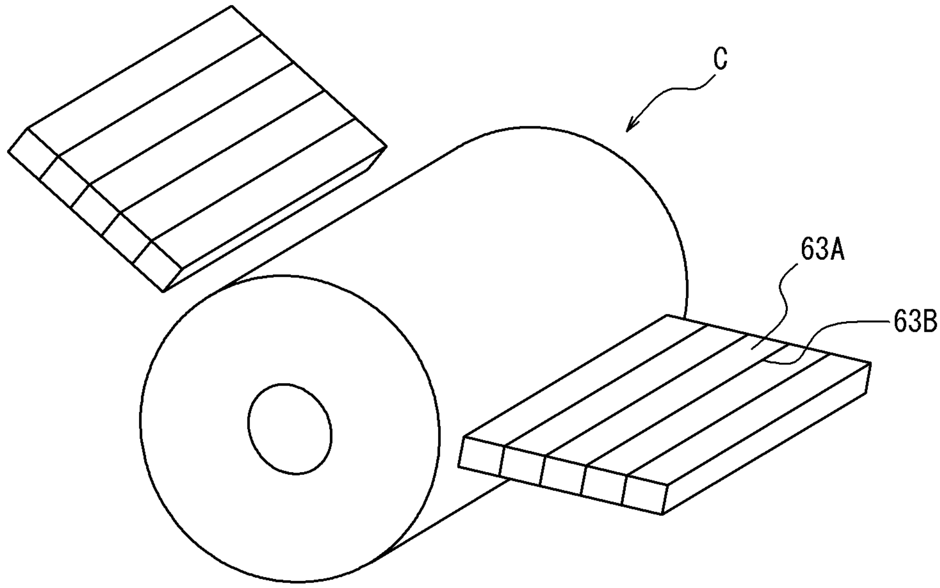


FIG. 2B

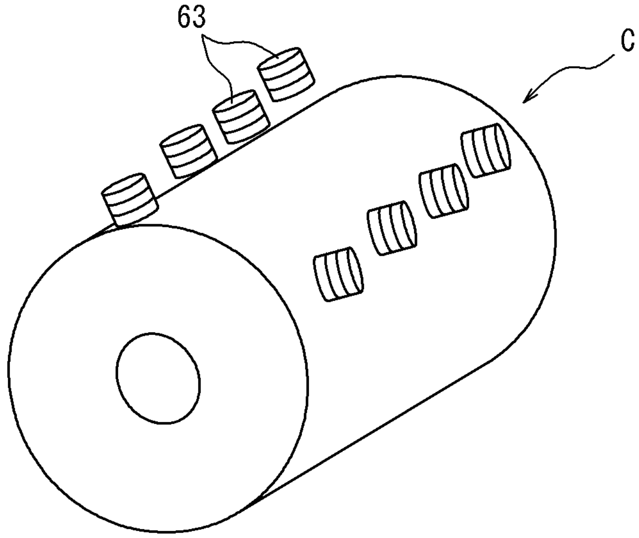


FIG. 3A

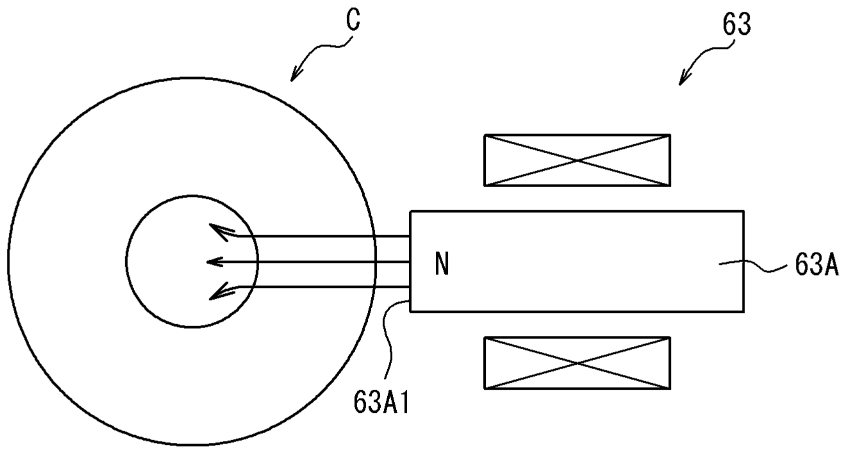


FIG. 3B

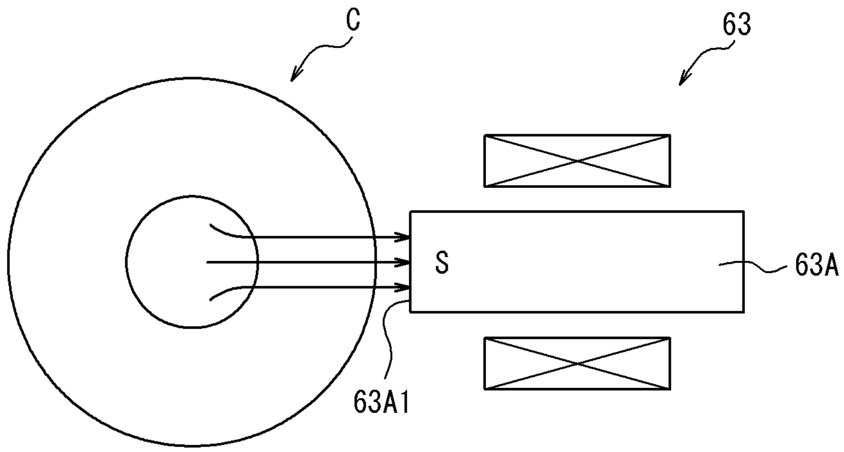


FIG. 4A

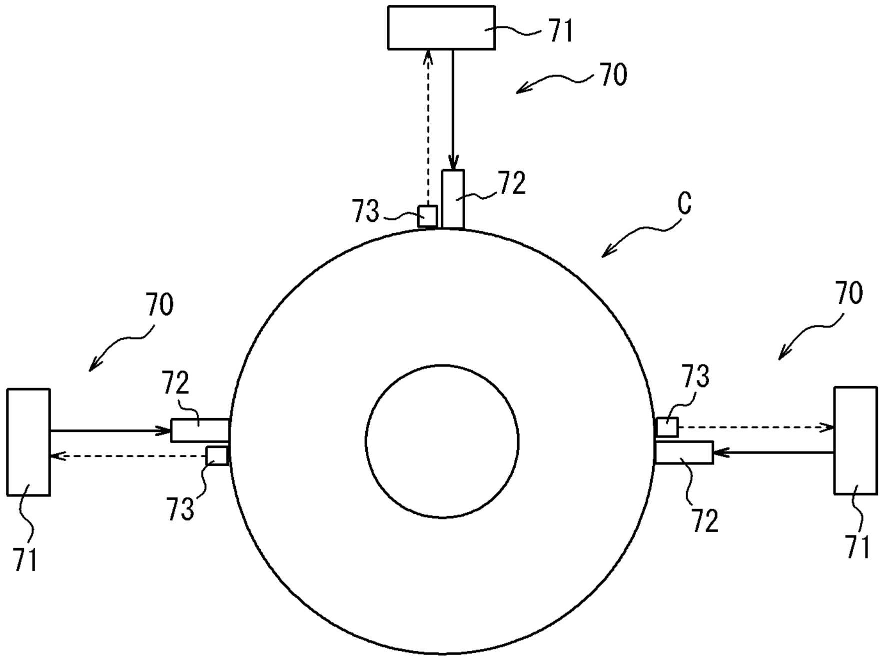


FIG. 4B

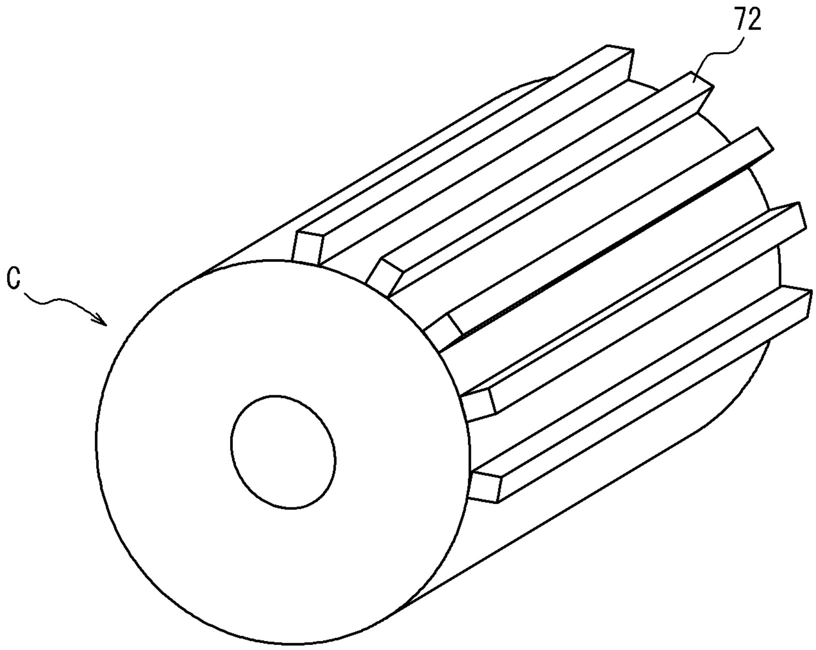


FIG. 5A

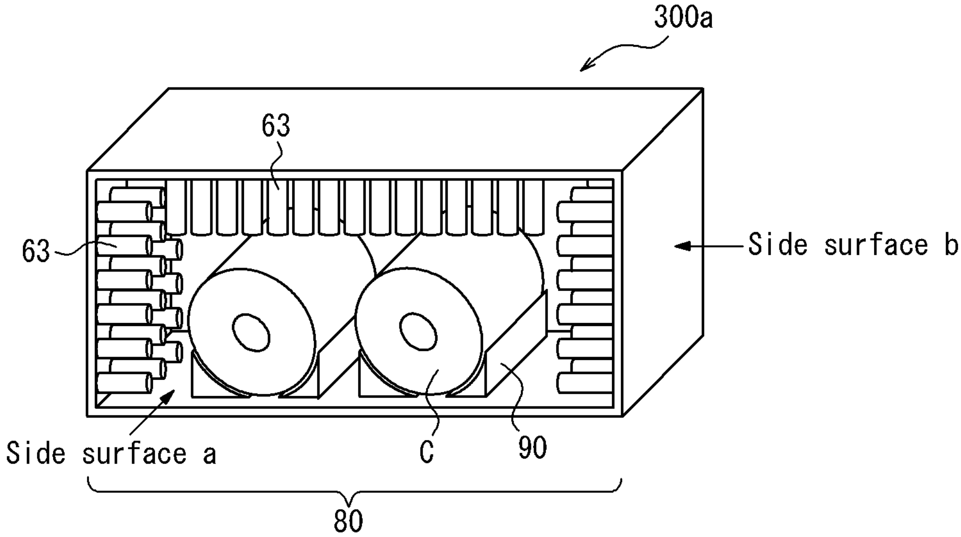


FIG. 5B

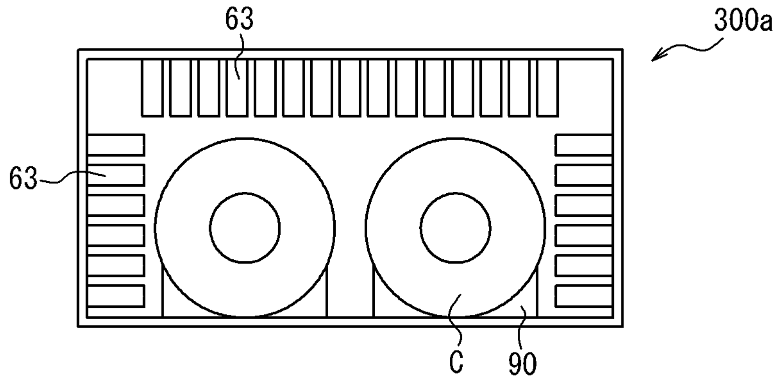


FIG. 5C

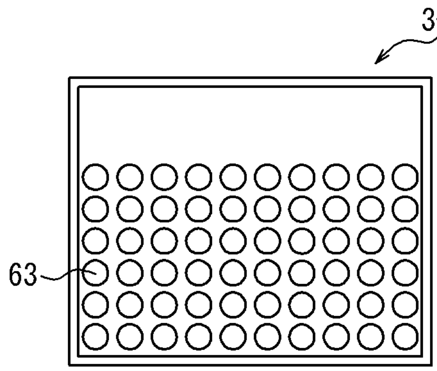


FIG. 5D

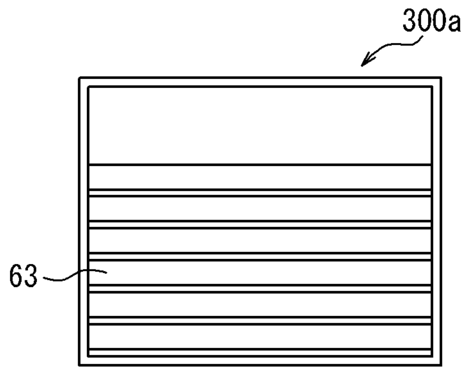


FIG. 6

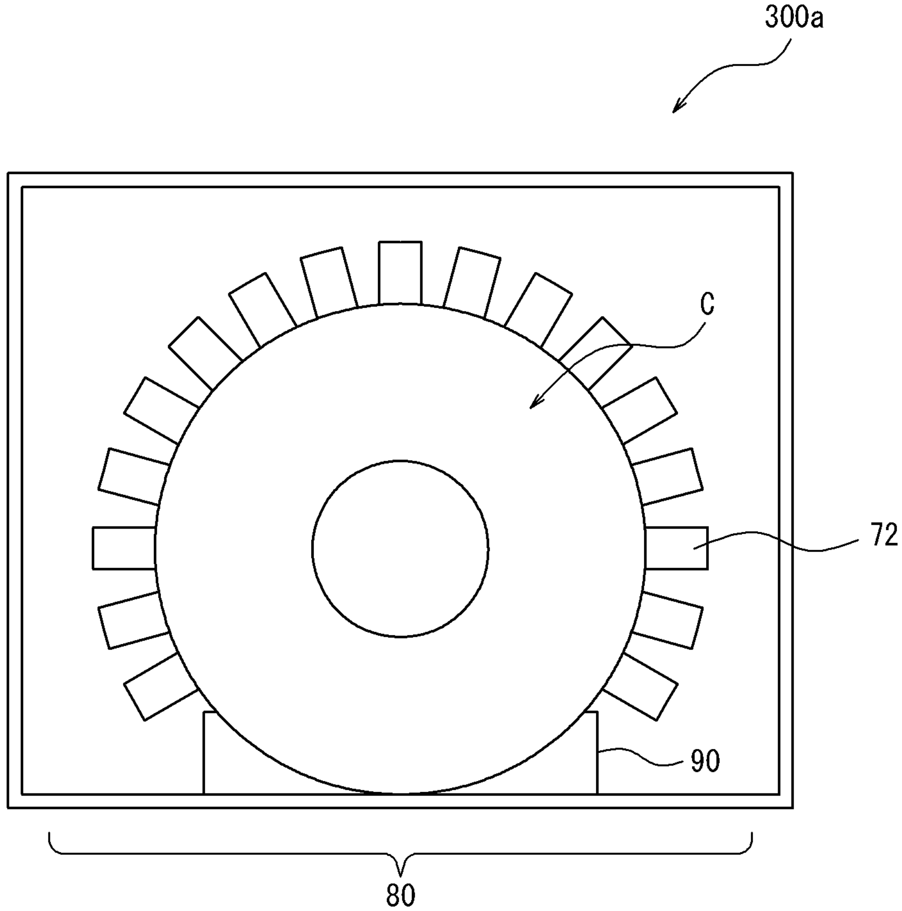


FIG. 7

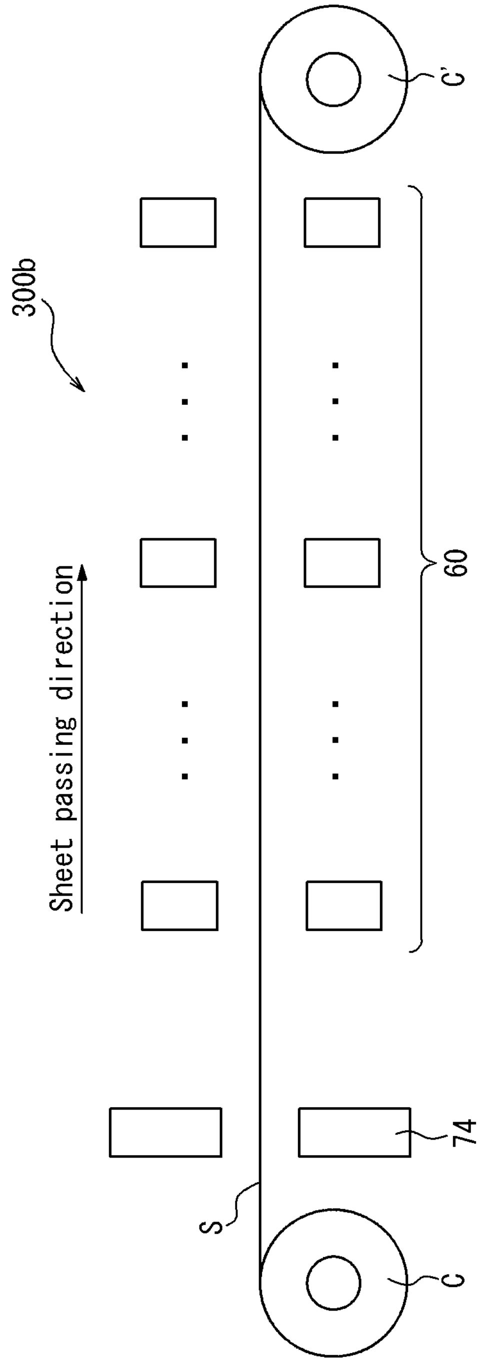
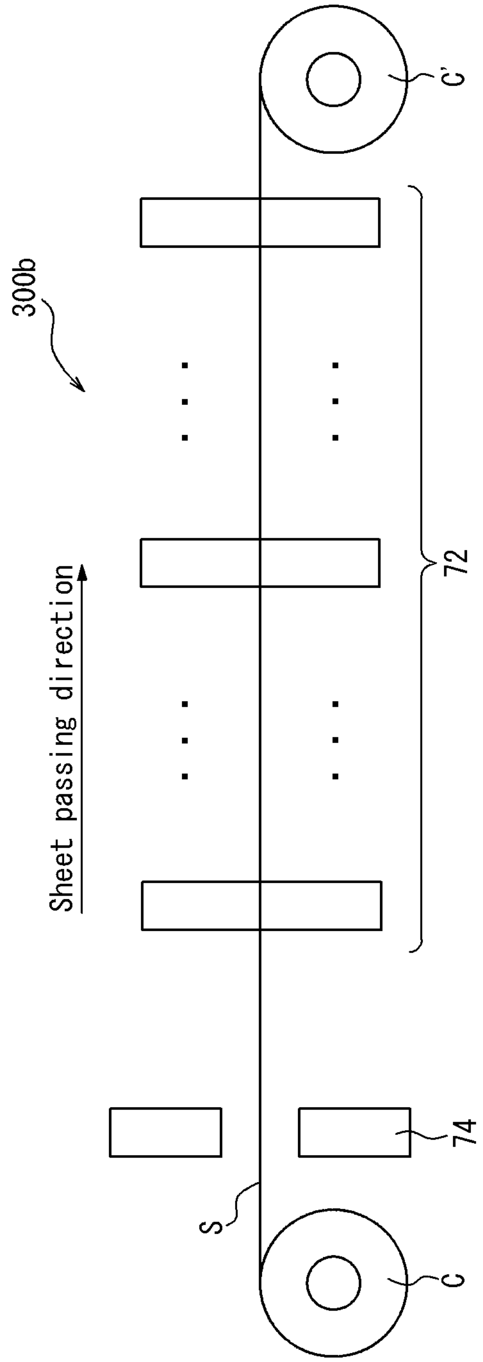


FIG. 8



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/020580

A. CLASSIFICATION OF SUBJECT MATTER

C21D 3/06(2006.01)i; ***C21D 9/46***(2006.01)i; ***C22C 38/00***(2006.01)i; ***C22C 38/06***(2006.01)i; ***C22C 38/58***(2006.01)i; ***C22C 38/60***(2006.01)i; ***C23C 2/00***(2006.01)i; ***C23C 2/06***(2006.01)i; ***C23C 2/40***(2006.01)i
FI: C21D3/06; C21D9/46 F; C21D9/46 J; C21D9/46 P; C21D9/46 Q; C21D9/46 S; C21D9/46 U; C22C38/00 301T; C22C38/00 301U; C22C38/00 301W; C22C38/00 302A; C22C38/00 302Z; C22C38/06; C22C38/58; C22C38/60; C23C2/00; C23C2/06; C23C2/40

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)

C21D3/06; C21D9/46-9/48; C22C38/00-38/60; C23C2/00-2/40; C21D9/52-9/66

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2022
Registered utility model specifications of Japan 1996-2022
Published registered utility model applications of Japan 1994-2022

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2020-153003 A (JFE STEEL CORP) 24 September 2020 (2020-09-24) claims, paragraphs [0024]-[0025], [0044], [0059]-[0069], fig. 3	5, 7-8, 10-11, 20, 22-23, 30-32
A		1-4, 6, 9, 12-19, 21, 24-29, 33-35
X	JP 50-098422 A (NIPPON STEEL CORPORATION) 05 August 1975 (1975-08-05) claims, p. 1, lower right column, lines 12-15, p. 3, upper right column, line 7 to p. 4, upper right column, line 19	5, 7-8, 11, 20, 23, 30-34
A		1-4, 6, 9-10, 12-19, 21-22, 24-29, 35
X	JP 62-287019 A (NIPPON STEEL CORPORATION) 12 December 1987 (1987-12-12) claims, p. 3, upper right column, line 5 to p. 4, upper left column, line 8, fig. 5	5-6, 10, 20-22, 30-34
A		7-9, 11-19, 23-29, 35

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

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"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 July 2022	**02 August 2022**

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office (ISA/JP) **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/020580

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2004-131794 A (NIPPON STEEL CORPORATION) 30 April 2004 (2004-04-30)	1-35

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/020580

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2020-153003 A	24 September 2020	EP 3907304 A1 claims, paragraphs [0032]-[0033], [0075], [0101]-[0112], fig. 3	
JP 50-098422 A	05 August 1975	(Family: none)	
JP 62-287019 A	12 December 1987	(Family: none)	
JP 2004-131794 A	30 April 2004	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 6562180 B **[0003] [0004]**
- WO 2019188642 A1 **[0003] [0004]**