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

(57) An object is to provide, in controlled cooling in which a hot-rolled steel plate is cooled while being constrained by rolls, a steel-plate cooling method with a less distortion, a steel-plate cooling apparatus, and a steel-plate manufacturing method.

A steel-plate cooling method includes conveying a steel plate in a state of being constrained by a plurality of rolls disposed at a predetermined pitch in a steel-plate conveying direction and cooling the steel plate by jetting a cooling water onto upper and lower surfaces of the steel plate by using cooling nozzles disposed between the plurality of rolls.

The cooling is performed at a plate passage speed V that satisfies a formula (1) below.

$$V > 2.21 \times 10^{-5} \times C_v \times L^3 \times t^{-2} \times (24.2 + 204.3 \times (L/W)^2)^{-1} \dots (1),$$

where, in the formula (1),

V : plate passage speed (m/s),

C_v : cooling speed ($^{\circ}\text{C/s}$) with respect to a steel-plate average temperature in a plate thickness direction,

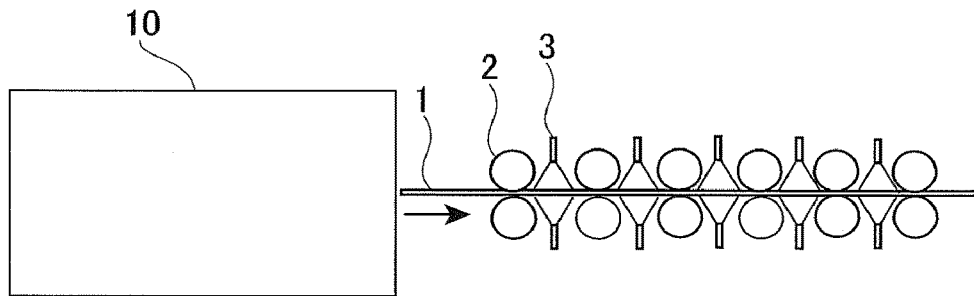
L : roll pitch (m),

t : plate thickness (m), and

W : plate width (m).

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FIG. 1



Description

Technical Field

[0001] The present invention relates to controlled cooling in which a hot-rolled high-temperature steel plate in a state of being constrained by rolls is subjected to passage-cooling. The present invention relates, in particular, to a steel-plate cooling method, a steel-plate cooling apparatus, and a steel-plate manufacturing method that are capable of manufacturing a thick steel plate (hereinafter, also simply referred to as the steel plate) having a thin plate thickness of 10 mm or less and a plate width of 3000 mm or more with a less distortion.

Background Art

[0002] To manufacture a steel plate, it is required to ensure mechanical characteristics, in particular, strength and toughness, required for the steel plate. To achieve this, work in which, for example, a rolled high-temperature steel plate is cooled in such a state and reheated/quenched offline after being air-cooled to room temperature is performed. In this cooling, the speed of the cooling is required to be increased to ensure material characteristics required for the steel plate. At the same time, it is important, for suppressing generation of a distortion during cooling (cooling-distortion) by ensuring uniformity of materials, to cool the entire surface of the steel plate uniformly. When a cooling-distortion is generated, it is required to ensure flatness of a steel plate after cooling by using a straightening machine, such as a roller straightening machine or a press, which generates an additional process and thus greatly hinders a reduction in delivery time.

[0003] To address the above circumstance, existing cooling of steel plates commonly employs a technique (known as passage-cooling) in which a steel plate is constrained by a plurality of rolls, a cooling nozzle is disposed between the constraining rolls, and the steel plate is cooled while being passed therethrough, thereby manufacturing a steel plate with a less distortion.

[0004] One of reasons for controlling cooling by such a method is that passage-cooling enables cooling to be performed in short-length equipment and thus enables initial investment costs to be suppressed. Moreover, the constraining rolls suppress generation of a distortion caused by nonuniformity of temperature distribution on upper and lower surfaces of a steel plate under cooling and in the surfaces of the steel plate, and the cooling nozzle that is disposed between the rolls suppresses a cooling water from being placed outside a cooling apparatus, thereby preventing the cooling water from remaining on the steel plate.

[0005] From a point of view of the above, for example, Patent Literature 1 describes a method of determining whether straightening is required for a shape defect caused by nonuniformity of temperature distribution in a steel plate after cooling by estimating residual stress generated in the steel plate on the basis of measurement of temperature distribution in the steel plate after cooling.

[0006] In addition, from a point of view of suppressing camber to be generated during water-cooling, Patent Literature 2 focuses on constraining rolls and describes a method of manufacturing a steel plate having excellent flatness by applying a load within a range of constraining force of the constraining rolls required as a function for the roll pitch thereof and the thickness of a steel plate.

Citation List

Patent Literature

[0007]

PTL 1: Japanese Patent No. 2843273

PTL 2: Japanese Patent No. 3925789

Summary of Invention

Technical Problem

[0008] Although the aforementioned method enables manufacture of steel plates with a less distortion, there is a case in which a distortion is still generated, even when temperature uniformity in a width direction and on upper and lower surfaces is ensured. As a result of the inventors of the present invention examining generation of distortions, it is found that a cooling-distortion is caused by a buckling strain due to contraction in the width direction of a steel plate during water-cooling. It is found that, when a steel plate has a thin plate thickness and a wide plate width, the reduction effect

by the aforementioned method is not easily exerted for a cooling-distortion caused by a buckling strain and that, even when temperature uniformity in the width direction and on upper and lower surfaces is ensured, a distortion is generated during cooling of, in particular, a steel plate having a plate thickness of 10 mm or less and a plate width of 3000 mm or more.

[0009] It is considered that a distortion is generated even when cooling is performed by an existing method because the mechanism of buckling strains due to contraction in the width direction of a steel plate during water-cooling differs from the mechanism of assumed distortions due to a temperature deviation between upper and lower surfaces. In a method, such as that described in Patent Literature 1, in which estimation is performed on the basis of temperature distribution in a steel plate after cooling, a strain larger than an estimated plate shape is generated. Thus, estimation fails, which makes it difficult to reduce occurrence of straightening. In Patent Literature 2, it is possible to suppress distortions due to a temperature deviation between upper and lower surfaces; however, an effect is not exerted for a region having a thin plate thickness and a wide plate width because buckling strains due to contraction in the plate width during water-cooling is not considered.

[0010] To solve the aforementioned problems of existing technology, an object of the present invention is to provide a steel-plate cooling method with a less distortion, a steel-plate cooling apparatus, and a steel-plate manufacturing method in controlled cooling in which a hot-rolled steel plate is cooled while being constrained by rolls.

Solution to Problem

[0011] An outline of the present invention is as follows.

[1] A steel-plate cooling method including conveying a steel plate in a state of being constrained by a plurality of rolls disposed at a predetermined pitch in a steel-plate conveying direction and cooling the steel plate by jetting a cooling water onto upper and lower surfaces of the steel plate by using cooling nozzles disposed between the plurality of rolls,

in which the cooling is performed at a plate passage speed V that satisfies the formula (1) below:

$$V > 2.21 \times 10^{-5} \times C_v \times L^3 \times t^{-2} \times (24.2 + 204.3 \times (L/W)^2)^{-1} \dots (1),$$

where, in the formula (1),

V : plate passage speed (m/s),

C_v : cooling speed ($^{\circ}\text{C/s}$) with respect to a steel-plate average temperature in a plate thickness direction,

L : roll pitch (m),

t : plate thickness (m), and

W : plate width (m).

[2] The steel-plate cooling method described in [1], in which the plate thickness t is 10 mm or less.

[3] The steel-plate cooling method described in [1] or [2], in which the plate width W is 3000 mm or more.

[4] A steel-plate cooling apparatus comprising:

a plurality of rolls that are disposed at a predetermined pitch in a steel-plate conveying direction and that constrain and convey a steel plate;

cooling nozzles that are disposed between the plurality of rolls and that cools the steel plate by jetting a cooling water onto upper and lower surfaces of the steel plate; and

a control mechanism that controls a plate passage speed V so as to satisfy the formula (1) below,

$$V > 2.21 \times 10^{-5} \times C_v \times L^3 \times t^{-2} \times (24.2 + 204.3 \times (L/W)^2)^{-1} \dots (1),$$

where, in the formula (1),

V : plate passage speed (m/s),

C_v : cooling speed ($^{\circ}\text{C/s}$) with respect to a steel-plate average temperature in a plate thickness direction,

L: roll pitch (m),
t: plate thickness (m), and
W: plate width (m).

- [5] The steel-plate cooling apparatus described in [4], in which the plate thickness t is 10 mm or less.
[6] The steel-plate cooling apparatus described in [4] or [5], in which the plate width W is 3000 mm or more.
[7] A steel-plate manufacturing method comprising cooling a hot-rolled steel plate by using the steel-plate cooling method described in any one of [1] to [3], thereby manufacturing a steel plate.

Advantageous Effects of Invention

[0012] According to the present invention, manufacture of a steel plate with a less distortion is enabled. The present invention is capable of exerting the effect thereof by being applied, in particular, to off-line heat treatment of a thick steel plate.

Brief Description of Drawings

[0013]

- Fig. 1 is a schematic view illustrating a configuration of part of manufacturing equipment that use a steel-plate cooling apparatus according to the present invention.
Fig. 2 is a view describing a buckling strain during cooling of a steel plate; (a) is a schematic view illustrating a configuration of the cooling apparatus according to the present invention, and (b) is a view describing a change in a plate width W of a steel plate during cooling of the steel plate.
Fig. 3 is a view illustrating an example of a shape defect (edge waves) of a steel plate.
Fig. 4 is a view describing the definition of a steepness λ .
Fig. 5 is a view illustrating a relationship between a roll pitch L and a steepness λ .
Fig. 6 is a view illustrating a relationship between a cooling speed C_v and a steepness λ .
Fig. 7 is a view illustrating a relationship between a plate passage speed V and a steepness λ .
Fig. 8 is a view describing a buckling strain when a portion of a steel plate (steel plate in a roll pitch L) is cut out.
Fig. 9 is a view illustrating a relationship between a buckling coefficient k and the square of a roll pitch L and a plate width W .

Description of Embodiments

[0014] First, a buckling strain due to contraction in the width direction of a steel plate during cooling, the buckling strain being considered a cause of a cooling-distortion, will be described. Fig. 1 is a schematic view illustrating a configuration of part of manufacturing equipment that use a steel-plate cooling apparatus according to the present invention. A steel plate 1 manufactured in a rolling mill line and having a predetermined plate thickness is conveyed to a manufacturing line in Fig. 1. After the steel plate 1 is heated by a heating furnace 10 to a predetermined temperature, the steel plate 1 is conveyed while being constrained by a plurality of rolls 2, and cooling of the steel plate 1 is performed by using a plurality of cooling nozzles 3 that are each set between rolls 2. The arrow in Fig. 1 indicates a conveying direction of the steel plate. The rolls 2 and the cooling nozzles 3 are set at upper and lower surfaces of the steel plate 1. The cooling apparatus according to the present invention includes the rolls 2, the cooling nozzles 3, and a control mechanism (not illustrated) that controls a plate passage speed V to satisfy a formula (1), which is described below.

[0015] Fig. 2(a) is a schematic view illustrating a configuration of the steel-plate cooling apparatus according to the present invention. As illustrated in Fig. 2(a), the steel plate 1 is constrained at the upper and lower surfaces thereof by the plurality of rolls 2, such as rolls 2-0, rolls 2-1, ... rolls 2-i, and rolls 2-n, in the conveying direction. The cooling nozzles 3 are each set between the rolls 2 so as to be at the upper and lower surfaces of the steel plate 1.

[0016] Fig. 2(b) is a view describing a change in the plate width W of a steel plate during cooling of the steel plate and is a top view of the change in the plate width W of the steel plate 1 during passage in the steel-plate cooling apparatus illustrated in Fig. 2(a). The plate width of the steel plate 1 during passage through the rolls 2 is represented by W , and a roll pitch in the steel-plate conveying direction is represented by L . The steel plate 1 contracts due to water-cooling. For example, when the steel plate is moved from the rolls 2-0 to the rolls 2-1, the plate width decreases by ΔW ($\Delta = W_0 - W_1$; W_0 is a plate width during passage through the rolls 2-0, and W_1 is a plate width during passage through the rolls 2-1), as illustrated in Fig. 2(b). At this time, a portion having a wide plate width (for example, the plate width W_0) is subjected to large compressive stress because the portion is in a state identical to a state in which a steel plate having a wide plate width and a steel plate having a narrow plate width are joined to each other so as to have the same width.

A strain of the steel plate due to the compressive stress is referred to as a buckling strain in the present invention.

[0017] At this time, when the plate passage speed is slow or when the cooling speed is fast, a contraction gradient $\Delta W/L$ in the conveying direction is steep, which generates large compressive stress and causes a buckling strain to be generated easily. When the plate thickness is thin and the plate width is wide, the rigidity of the plate is low, which

decreases resistance to the compressive stress and similarly causes a buckling strain to be generated easily.
[0018] To confirm a mechanism of the aforementioned contraction in the plate width W , a relationship between the shape of a steel plate cooled under various conditions, such as a plate passage speed V , a plate thickness t , a plate width W , a cooling speed C_v , and the like, and each cooling condition was examined in an actual manufacturing line. Specifically, after the steel plate 1 manufactured in the rolling mill line and having a plate thickness of 6 mm to 10 mm was conveyed to the manufacturing line in Fig. 1 and heated by the heating furnace 10 (hearth-roll heating furnace) to 950°C, the steel plate 1 was cooled by using the cooling nozzles 3 to 100°C while being constrained by the rolls 2. Generation of a buckling strain was determined on the basis of the shape of the steel plate after cooling.

[0019] Fig. 3 is a view of an example illustrating the shape of a steel plate in which a shape defect is generated. A shape defect, which is known as edge waves, was generated in edge portions of the steel plate 1. The defect of wave-shaped edges was quantified using the steepness λ (%) represented with the definitions indicated in Fig. 4 and in the formula (2) below. Edge waves are not generated at one location; a plurality of edge waves are generated at both end portions of a steel plate. Thus, the value of δ/P in the formula (2) below is an average value of all edge waves generated at both end portions of the steel plate.

$$\lambda = (\delta/P) \times 100 \dots (2)$$

[0020] Note that, in the formula (2),

λ : steepness (%),
 δ : wave height (m), and
 P : wave pitch (m).

[0021] As a result of the quantification, the wave pitch P of the steel plate in which a shape defect is generated was approximately 0.6 to 1.4 m. With regard to a tolerance of the steepness, it is preferable that the steepness be small as much as possible because, for example, presence of large shape defects during welding of a plurality of plates generates work of, for example, performing the welding in a state in which strains included in the steel plates are constrained and flattened. As a general standard, when the wave pitch P in the steel-plate conveying direction is set to 2 m, the wave height δ is required to be set to 10 mm or less. Thus, in the present invention, when the steepness $\lambda = (10/2000) \times 100 =$ less than 0.5%, it is considered that no buckling strain is present, and, when λ is 0.5% or more, it is determined that a buckling strain is present.

[0022] Fig. 5 is a view illustrating a relationship between the roll pitch L and the steepness λ of the edge wave shape, with the plate thickness $t = 10$ mm, the plate width $W = 3000$ mm, the plate passage speed $V = 0.58$ m/s, and the cooling speed $C_v = 220^\circ\text{C/s}$. It was confirmed that the shorter the roll pitch L , the smaller the steepness λ . When the roll pitch L is 600 mm or less, no edge waves were generated.

[0023] Fig. 6 is a view illustrating a relationship between the cooling speed C_v and the steepness λ of the edge wave shape, with the plate thickness $t = 10$ mm, the plate width $W = 3000$ mm, the plate passage speed $V = 0.58$ m/s, and the roll pitch $L = 750$ mm. It was confirmed that the smaller the cooling speed C_v , the smaller the steepness λ . When the cooling speed C_v is 110°C/s or less, no edge waves were generated.

[0024] Fig. 7 is a view illustrating a relationship between the plate passage speed V and the steepness λ for each of a steel plate having a plate width W of 1500 mm and a steel plate having a plate width W of 3000 mm, with the plate thickness $t = 6$ mm, the roll pitch $L = 750$ mm, and the cooling speed $C_v = 300^\circ\text{C/s}$. It was confirmed that the faster the plate passage speed V , the smaller the steepness λ regardless of the plate width. When the plate width W is 1500 mm, no edge waves were generated at the plate passage speed V of 1.8 m/s or more. When the plate width W is 3000 mm, no edge waves were generated at the plate passage speed V of 3.0 m/s or more. From these results, it was found that, when the plate passage speed is same, the larger the plate width, the worse the shape.

[0025] In a thick steel plate, the thicker the plate thickness, the more the temperature difference generated during cooling between a steel plate surface and a steel plate center. Thus, the cooling speed C_v here is the cooling speed with respect to an average temperature in the plate thickness direction.

[0026] From these knowledges, a buckling strain is considered to be generated due to the plate passage speed V , the cooling speed C_v , the roll pitch L , the plate thickness t , and the plate width W . As a result of the inventors of the present invention further examining, it is found that no buckling strain is generated when the plate passage speed V

represented by the formula (1) below is satisfied and it is possible to obtain a steel plate with a less distortion.

$$V > 2.21 \times 10^{-5} \times C_v \times L^3 \times t^{-2} \times (24.2 + 204.3 \times (L/W)^2) \dots (1),$$

where, in the formula (1),

V: plate passage speed (m/s),

C_v: cooling speed (°C/s) with respect to a steel-plate average temperature in the plate thickness direction

L: roll pitch (m),

t: plate thickness (m), and

W: plate width (m).

[0027] Hereinafter, derivation of the formula (1) above will be described.

[0028] According to the danseigaku handbook (handbook of theory of elasticity) (Nakahara et al., 2001, Asakura Publishing Co., Ltd., P. 264), the compressive stress of a buckling limit is described as follows. [Formula 1]

$$\sigma_e = \frac{kE\pi^2}{12(1-\nu^2)} \left(\frac{t}{L} \right)^2 \dots (3)$$

[Formula 2]

$$k = \left(\frac{mL}{W} \right)^2 + 2 + \left(\frac{W}{mL} \right)^2 \dots (4)$$

[0029] In the above formulas,

σ_e: buckling limit stress (MPa),

k: buckling coefficient,

E: Young's modulus (MPa),

π: circular constant,

ν: Poisson's ratio,

t: plate thickness (m),

L: roll pitch (m),

W: plate width (m), and

m: wavenumber (normally, 1).

[0030] Note that, although L is indicated as a plate length in the handbook of theory of elasticity, it is determined from the direction of stress to read L as a roll pitch since rolls are used to constrain a plate in the system here. With regard to the buckling coefficient k, the formula (4) is an example of an initial analysis. The buckling coefficient is actually not as indicated by the formula (4) since the constrained state and the like of steel plates vary. Thus, the buckling coefficient k is often utilized by being corrected with reference to the formula (4), as appropriate, to correspond to an actual state.

[0031] With reference to a portion of a steel plate between some of the rolls (steel plate in the roll pitch L) being cut out as illustrated in Fig. 8, compressive stress applied to the steel plate in the width direction is derived from an inter-rolls input temperature and an inter-rolls output temperature and can be described as follows. [Formula 3]

$$\sigma_a = \alpha E (T_{in} - T_{out}) \dots (5)$$

[0032] In the above formula,

σ_a : compressive stress (MPa) in the width direction,
 α : linear expansion coefficient (1/°C),
 E : Young's modulus (MPa),
 T_{in} : inter-rolls input temperature (°C), and
 T_{out} : inter-rolls output temperature (°C).

[0033] If cooling is performed between the rolls at a constant cooling speed, the inter-rolls input temperature T_{in} and the inter-rolls output temperature T_{out} in the formula (5) above can be described as follows. [Formula 4]

$$(T_{in} - T_{out}) = \frac{C_v \cdot L}{V} \quad \cdot \cdot \cdot (6)$$

[0034] In the above formula,

C_v : cooling speed (°C/s) and
 V : plate passage speed (m/s).

[0035] In other words, the compressive stress σ_a in the width direction can be described as follows. [Formula 5]

$$\sigma_a = \alpha E \frac{C_v \cdot L}{V} \quad \cdot \cdot \cdot (7)$$

[0036] When the compressive stress σ_a in the width direction is smaller than the buckling limit stress σ_e , no buckling is generated; therefore, when the relational expression of the formula (8) is satisfied, no buckling strain is generated. [Formula 6]

$$\sigma_e = \frac{kE\pi^2}{12(1-\nu^2)} \left(\frac{t}{L} \right)^2 > \sigma_a = \alpha E \frac{C_v \cdot L}{V} \quad \cdot \cdot \cdot (8)$$

[0037] The formula (8) is rewritten with respect to the plate passage speed V as follows. [Formula 7]

$$V > \frac{12(1-\nu^2)\alpha \cdot C_v \cdot L^3}{\pi^2 \cdot kt^2} \quad \cdot \cdot \cdot (9)$$

[0038] In steel, the Poisson's ratio ν and the thermal expansion coefficient α each have a specific value and thus is considered a constant, and the plate passage speed V at which no buckling strain is generated can be described as follows. (With operation being assumed to be performed in a high-temperature region, the Poisson's ratio ν and the thermal expansion coefficient α are respectively converted as $\nu = 0.3$ and $\alpha = 2.0 \times 10^{-5}$) [Formula 8]

$$V > 2.21 \times 10^{-5} \times \frac{C_v \cdot L^3}{kt^2} \quad \cdot \cdot \cdot (10)$$

[0039] The buckling coefficient k is expressed as the formula (11) below derived from the formula (10) above.

[Formula 9]

$$k = 2.21 \times 10^{-5} \times \frac{C_v \cdot L^3}{Vt^2} \quad \cdot \cdot \cdot (11)$$

[0040] The buckling coefficient k has a process-specific value; therefore, the buckling coefficient k was actually obtained through various experiments in an actual apparatus. To actually obtain the buckling coefficient k , the plate thickness t

of 5 to 15 mm, the plate width W of 3000 to 5000 mm, the roll pitch L of 500 to 750 mm, and the plate passage speed of 0.3 to 2.0 m/s were set as experimental conditions.

[0041] The buckling constant k at a border at which a buckling is actually generated is considered, from the formula (4) above, to relate to the square of the roll pitch L and the plate width W. As described above, the buckling coefficient k may be deviated from the theoretical formula of the formula (4) depending on constrain of each end portion, strain conditions, and the like; therefore, there is an example in which a member of (W/L) is omitted when, for example, shearing force is present. Accordingly, a relationship between the buckling coefficient k actually obtained in an actual apparatus with the member of (W/L) omitted and the square of the roll pitch L and the plate width W is plotted. Results thereof are indicated in Fig. 9. In Fig. 9, ○ indicates that the steepness λ is less than 0.5%, and × indicates that the steepness λ is 0.5% or more. From Fig. 9, a correlation is considered to be present between the buckling constant k at a border at which a buckling is actually generated and the steepness λ .

[0042] From the results in Fig. 9, the buckling coefficient k can be represented by the following relationship.

$$k = 204.3 (L/W)^2 + 24.2 \dots (12)$$

[0043] When the formula (10) and the formula (12) are combined, the plate passage speed V at which no buckling is generated can be represented by the formula (1) below.

$$V > 2.21 \times 10^{-5} \times C_v \times L^3 \times t^{-2} \times (24.2 + 204.3 \times (L/W)^2)^{-1} \dots (1)$$

[0044] Note that, in the formula (1),

V: plate passage speed (m/s),

C_v: cooling speed (°C/s) with respect to a steel-plate average temperature in the plate thickness direction,

L: roll pitch (m),

t: plate thickness (m), and

W: plate width (m).

[0045] The roll pitch L is a parameter derived from a mechanical configuration and is thus a parameter that is not changeable after mechanical equipment installation. The plate thickness t, the plate width W, and the cooling speed C_v are parameters relating to determination of characteristics of a commodity and are thus also not simply changeable. Thus, the plate passage speed V, which is a parameter changeable as appropriate, is focused to arrange the formula (1).

[0046] From the formula (1) above, it is found that, when the plate width is wide, as the plate thickness t decreases, as the roll pitch L increases, or as the cooling speed C_v increases, the plate passage speed V required for cooling to prevent a buckling strain from being generated increases. The roll pitch L, the cooling speed C_v, and the plate passage speed V are values specific to a cooling apparatus, and the plate thickness t and the plate width W are determined in accordance with a product. The cooling speed C_v is a flow rate of a cooling water of the cooling apparatus, the plate passage speed V is the number of rotations of table rolls, and both the cooling speed C_v and the plate passage speed V are changeable. Thus, preferably, the roll pitch of the cooling apparatus is previously designed in a designing step in accordance with the range of manufacturing varieties so as to be as short (for example, a pitch of 500 mm) as possible, the number of rotations of the table rolls is set to a value such that the table rolls rotate as fast (for example, to 2 m/s or more) as possible, and the adjustment range of the flow rate of the cooling water is also designed to be wide. When it is not possible to reduce the roll pitch L, for example, when an existing apparatus is utilized, reducing the cooling speed C_v by widening the adjustment range of the flow rate of the cooling water to enable cooling to be performed at a small flow rate is effective (for example, 100°C/s or less with the plate thickness of 10 mm). In a hot strip mill that manufactures hot-rolled steel strips or in online-controlled cooling of thick steel plates, the plate passage speed is approximately 2.5 m/s, which is relatively fast, with the plate thickness of 10 mm. Thus, such a buckling strain is not easily generated. In contrast, in cooling during off-line heat treatment of thick steel plates, water-cooling is performed in interlock with the extraction rate of a heating furnace, and the plate passage speed is thus approximately 1.0 m/s, which causes a buckling strain such as that described in the present invention to be generated easily.

[0047] Accordingly, the present invention is capable of manufacturing a steel plate with a less cooling-distortion by cooling the steel plate at the plate passage speed V that satisfies the formula (1) above. The present invention exerts an effect with respect to a steel plate that has a thin plate thickness and a wide plate width. In particular, the present invention is suitable for cooling of a thick steel plate that has a plate thickness of 10 mm or less and/or a plate width of 3000 mm or more and is applicable to off-line heat treatment of thick steel plates.

EXAMPLE 1

[0048] A steel plate was cooled using the manufacturing equipment illustrated in Fig. 1. The heating temperature in the heating furnace 10 was set to 930°C, and the plate thickness was set to 5 mm, 10 mm, and 12 mm, which is a plate thickness with which a buckling strain is easily generated. A plurality of flat sprays arranged adjacent to each other in the width direction were used as the cooling nozzles 3. The amount of the cooling water was changeable, the cooling speed for a thick steel plate having a plate thickness of 5 mm when a maximum amount of water is jetted was 400°C/s, and the cooling speed when a minimum amount of water is jetted was 100°C/s. When cooling is performed by changing only the plate thickness with a constant amount of the cooling water, the cooling speed is in inverse proportion to the plate thickness. Therefore, when the plate thickness is 10 mm, the maximum cooling speed is 200°C/s and the minimum cooling speed is 50°C/s. The roll pitch L was changed for each condition.

[0049] The shape of each steel plate was determined on the basis of the steepness λ . When the steepness λ was less than 0.5%, the shape of the steel plate was determined to be flat, and, when the steepness λ was 0.5% or more, the shape of the steel plate was determined to include a buckling strain. To obtain the steepness λ , δ/P was calculated from an average value of all of edge waves generated at both end portions of the steel plate.

[0050] Results are indicated in Table 1.

[Table 1]

Item	Plate Thickness t mm	Plate Width W mm	Plate Passage Speed V m/s	Cooling Speed Cv °C/s	Roll Pitch L mm	Buckling-Limit Plate Passage Speed Formula (1) m/s	Steel Plate Shape
Comparative Example 1	12	3000	0.2	167	750	0.29	Buckling Strain
Comparative Example 2	12	3000	0.2	125	750	0.22	Buckling Strain
Comparative Example 3	12	3000	0.2	167	650	0.21	Buckling Strain
Comparative Example 4	12	5000	0.2	167	750	0.38	Buckling Strain
Present Invention Example 1	12	1500	0.3	167	750	0.14	Flat
Present Invention Example 2	12	3000	0.3	167	750	0.29	Flat
Present Invention Example 3	12	3000	0.3	167	550	0.14	Flat
Present Invention Example 4	12	3000	0.3	83	750	0.15	Flat
Present Invention Example 5	12	5000	0.4	167	750	0.38	Flat
Comparative Example 5	10	3000	0.3	200	750	0.51	Buckling Strain
Comparative Example 6	10	3000	0.3	150	750	0.38	Buckling Strain
Comparative Example 7	10	3000	0.3	200	650	0.36	Buckling Strain

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(continued)

Item	Plate Thickness t mm	Plate Width W mm	Plate Passage Speed V m/s	Cooling Speed Cv °C/s	Roll Pitch L mm	Buckling-Limit Plate Passage Speed Formula (1) m/s	Steel Plate Shape
Comparative Example 8	10	5000	0.3	200	750	0.65	Buckling Strain
Present Invention Example 6	10	1500	0.4	200	750	0.25	Flat
Present Invention Example 7	10	3000	1.0	200	750	0.51	Flat
Present Invention Example 8	10	3000	0.3	200	550	0.24	Flat
Present Invention Example 9	10	3000	0.3	100	750	0.25	Flat
Present Invention Example 10	10	5000	0.8	200	750	0.65	Flat
Comparative Example 9	5	3000	0.3	400	750	4.04	Buckling Strain
Comparative Example 10	5	3000	0.3	200	750	2.02	Buckling Strain
Comparative Example 11	5	3000	0.3	400	650	2.88	Buckling Strain
Comparative Example 12	5	5000	0.3	400	750	5.19	Buckling Strain
Present Invention Example 11	5	1500	0.5	100	600	0.34	Flat
Present Invention Example 12	5	3000	0.8	100	600	0.59	Flat
Present Invention Example 13	5	3000	1.5	400	500	1.48	Flat
Present Invention Example 15	5	5000	2.0	400	500	1.69	Flat

$$\text{Formula (1): } 2.21 \times 10^{-5} \times C_v \times L^3 \times t^{-2} \times (24.2 + 204.3 \times (L/W)^2)^{-1}$$

[0051] In each of the present invention examples, cooling was performed at a plate passage speed faster than the plate passage speed V obtained by the formula (1). In each of the present invention examples, no buckling strain was generated, and the shape was flat. In contrast, in each of the comparative examples, cooling was performed at a plate passage speed slower than the plate passage speed V obtained by the formula (1). In each of the comparative examples,

a buckling strain was generated under each of the conditions. As a result, all of the steel plates in the comparative examples were shipped after being subjected to shape correction using a roller straightening machine after cooling. All of the steel plates in the present invention examples were able to be shipped directly, without being straightened again.

[0052] Control of the conveying speed of a general off-line heat treatment apparatus of thick steel plates is affected by a drive mechanism of a heating furnace, and speed control of approximately 0.02 to 0.5 m/s is generally possible for the conveying speed. As indicated in the results of the examples, shape adjustment is easy, in particular, under the experimental condition of the plate thickness of 12 mm, because the plate passage speed, that is, the conveying speed, obtained by the formula (1) of the present invention falls within the conveying-speed control range of the actual apparatus, even when the cooling speed is fast. Shape adjustment of the steel plates having a narrow plate width is also easy because the plate passage speed, that is, the conveying speed, similarly obtained by the formula (1) of the present invention falls within the conveying-speed control range of the actual apparatus. Meanwhile, in particular, in control of the cooling speed, change in the roll pitch, and the like of the present invention in a steel plate having a plate thickness of 10 mm or less and/or a plate width of 3000 mm or more, the plate passage speed, that is, the conveying speed, obtained by the formula (1) of the present invention is sometimes out of the conveying-speed control range of the actual apparatus. Thus, it is found that, when the present invention is applied to a steel plate having a plate thickness of 10 mm or less and/or a plate width of 3000 mm or more, control of the cooling speed, change in the roll pitch, and the like are required. It is also found that, under the conditions of a thin plate thickness of 5 mm and a plate width of 5000 mm, a buckling strain is prevented from being generated by narrowing the roll pitch to 500 mm and controlling the plate passage speed at 2.0 m/s, which is slightly faster than that in general facilities.

Reference Signs List

[0053]

1	steel plate
2	roll
2-0	roll
2-1	roll
2-i	roll
2-n	roll
3	cooling nozzle
10	heating furnace (hearth roll heating furnace)
δ	wave height
P	wave pitch

Claims

1. A steel-plate cooling method including conveying a steel plate in a state of being constrained by a plurality of rolls disposed at a predetermined pitch in a steel-plate conveying direction and cooling the steel plate by jetting a cooling water onto upper and lower surfaces of the steel plate by using cooling nozzles disposed between the plurality of rolls, wherein the cooling is performed at a plate passage speed V that satisfies a formula (1) below:

$$V > 2.21 \times 10^{-5} \times C_v \times L^3 \times t^{-2} \times (24.2 + 204.3 \times (L/W)^2)^{-1} \dots (1),$$

where, in the formula (1),

V: plate passage speed (m/s),

C_v: cooling speed (°C/s) with respect to a steel-plate average temperature in a plate thickness direction,

L: roll pitch (m),

t: plate thickness (m), and

W: plate width (m).

2. The steel-plate cooling method according to claim 1, wherein the plate thickness t is 10 mm or less.

3. The steel-plate cooling method according to claim 1 or claim 2, wherein the plate width W is 3000 mm or more.

4. A steel-plate cooling apparatus comprising:

a plurality of rolls that are disposed at a predetermined pitch in a steel-plate conveying direction and that constrain and convey a steel plate;
cooling nozzles that are disposed between the plurality of rolls and that cools the steel plate by jetting a cooling water onto upper and lower surfaces of the steel plate; and
a control mechanism that controls a plate passage speed V so as to satisfy a formula (1) below,

$$V > 2.21 \times 10^{-5} \times C_v \times L^3 \times t^{-2} \times (24.2 + 204.3 \times (L/W)^2)^{-1} \dots (1),$$

where, in the formula (1),

V: plate passage speed (m/s),

C_v: cooling speed (°C/s) with respect to a steel-plate average temperature in a plate thickness direction,

L: roll pitch (m),

t: plate thickness (m), and

W: plate width (m).

5. The steel-plate cooling apparatus according to claim 4, wherein the plate thickness t is 10 mm or less.

6. The steel-plate cooling apparatus according to claim 4 or claim 5, wherein the plate width W is 3000 mm or more.

7. A steel-plate manufacturing method comprising cooling a hot-rolled steel plate by using the steel-plate cooling method according to any one of claims 1 to 3, thereby manufacturing a steel plate.

FIG. 1

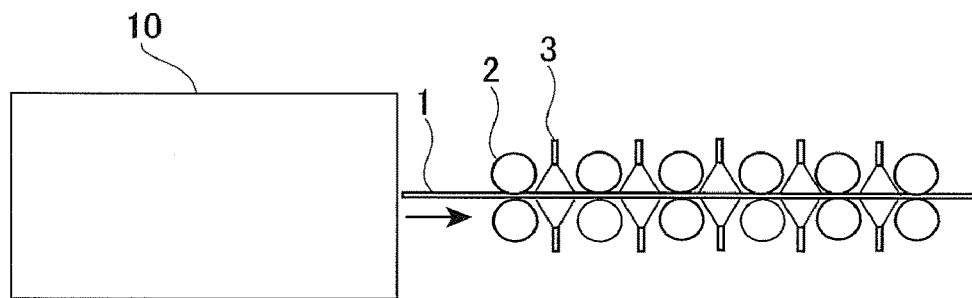


FIG. 2

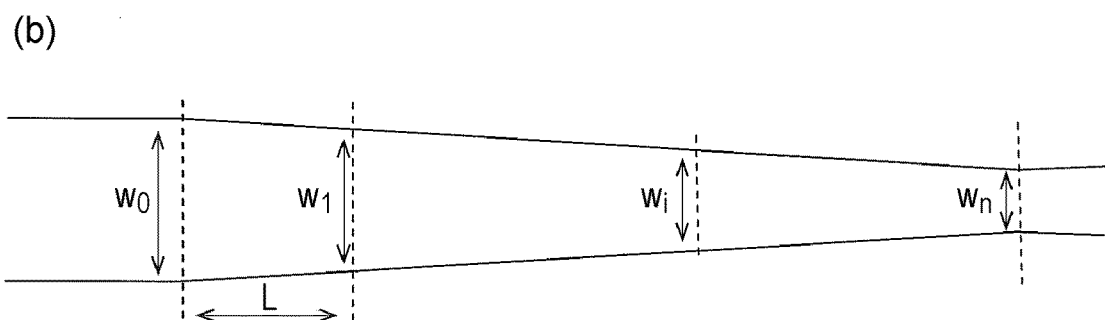
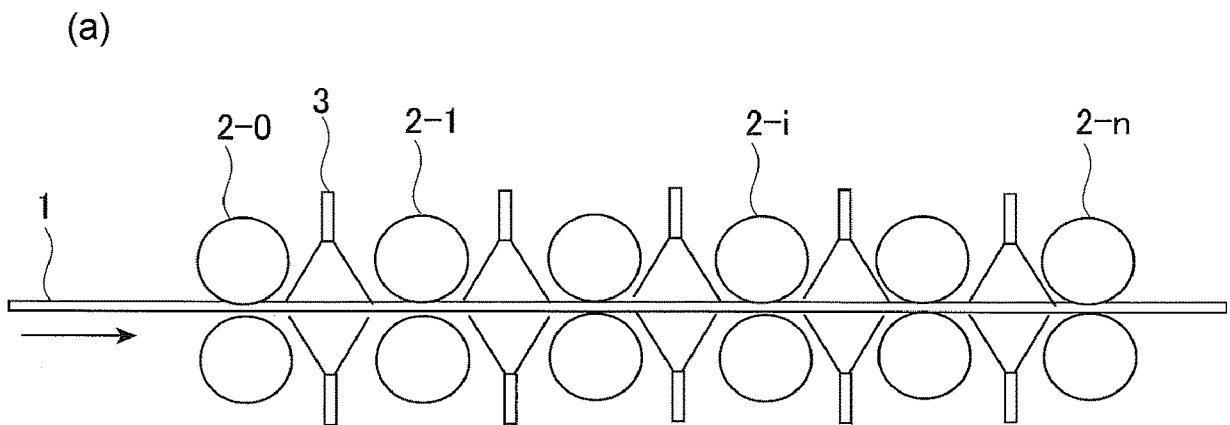


FIG. 3

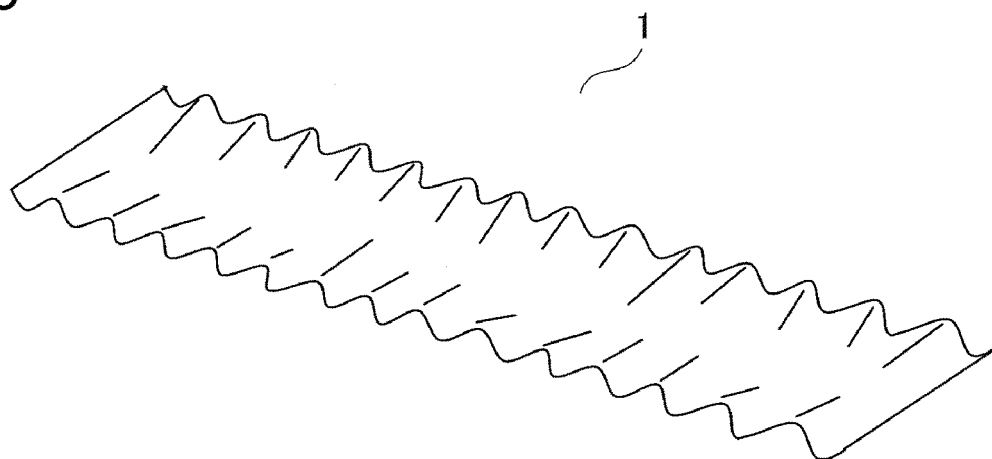


FIG. 4

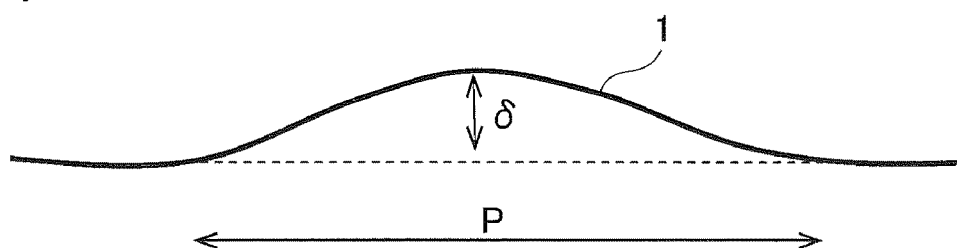


FIG. 5

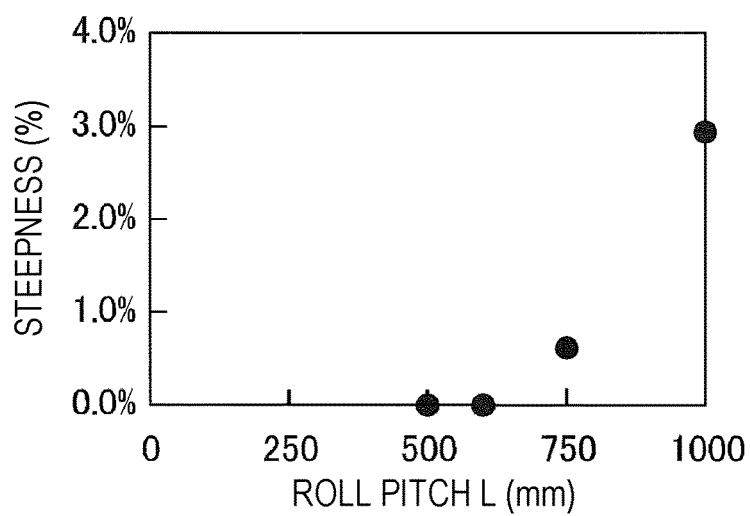


FIG. 6

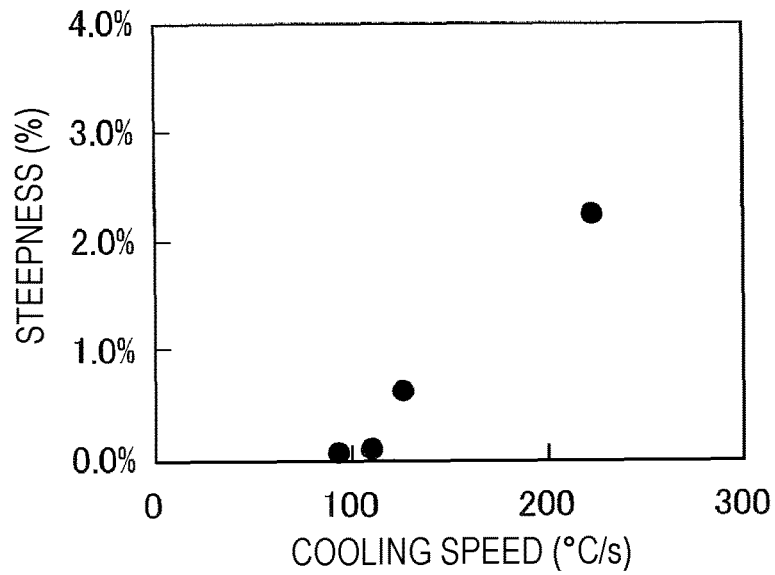


FIG. 7

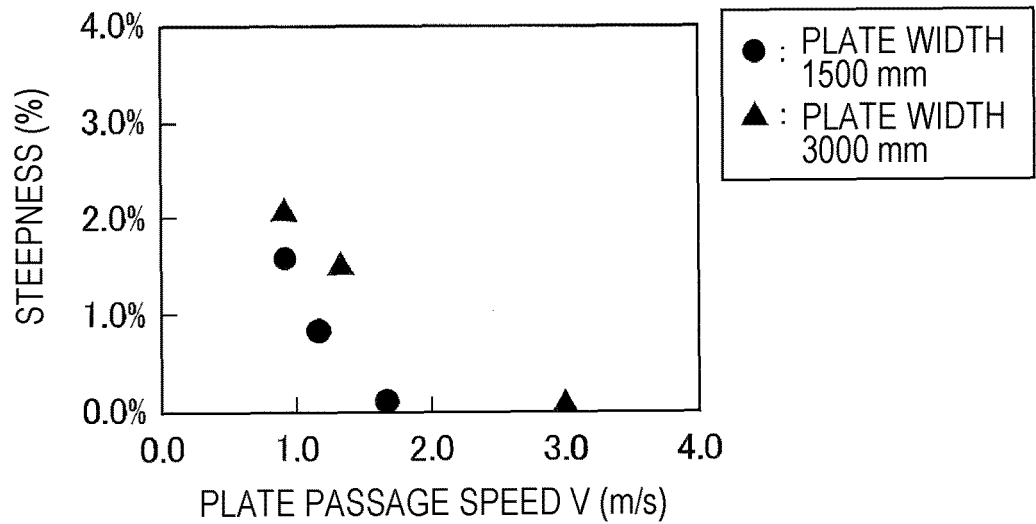


FIG. 8

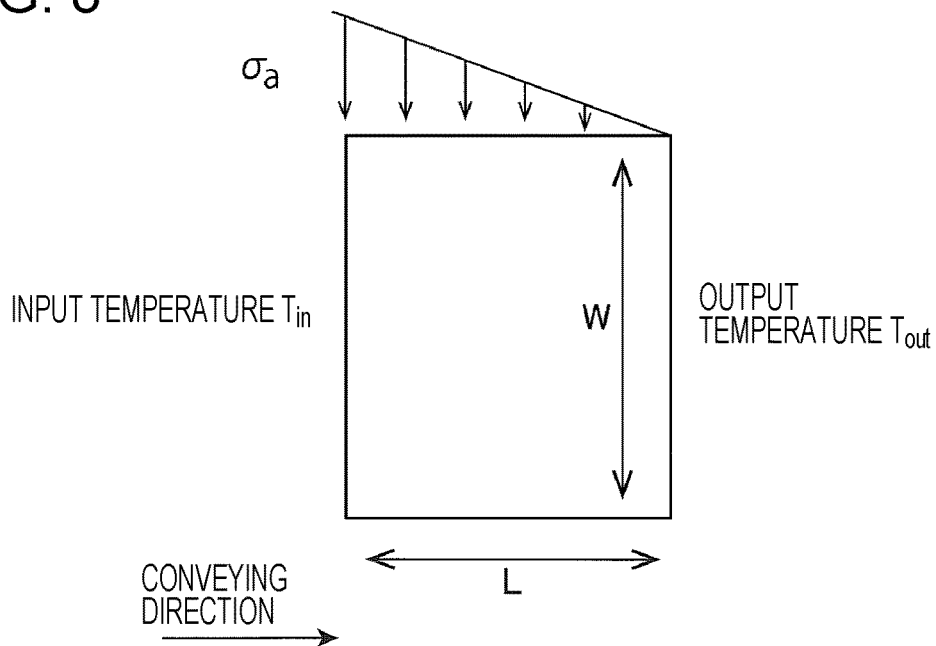
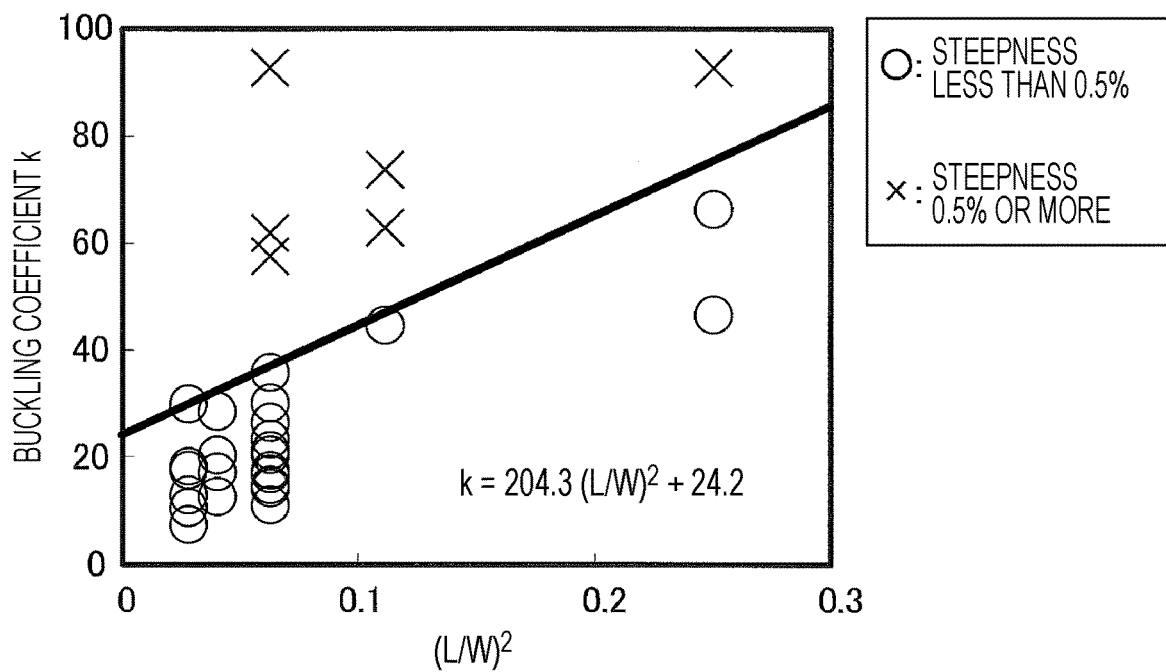


FIG. 9



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2018/007743

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. B21845/02 (2006.01) i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. B21845/02

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 1971-2018

Registered utility model specifications of Japan 1996-2018

Published registered utility model applications of Japan 1994-2018

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.
A	JP 2004-216438 A (NIPPON STEEL CORP.) 05 August 2004 (Family: none)	1-7
A	JP 02-179829 A (NIPPON STEEL CORP.) 12 July 1990 (Family: none)	1-7



Further documents are listed in the continuation of Box C.



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Date of the actual completion of the international search

06 April 2018 (06.04.2018)

Date of mailing of the international search report

17 April 2018 (17.04.2018)

Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

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Patent documents cited in the description

- JP 2843273 B [0007]
- JP 3925789 B [0007]