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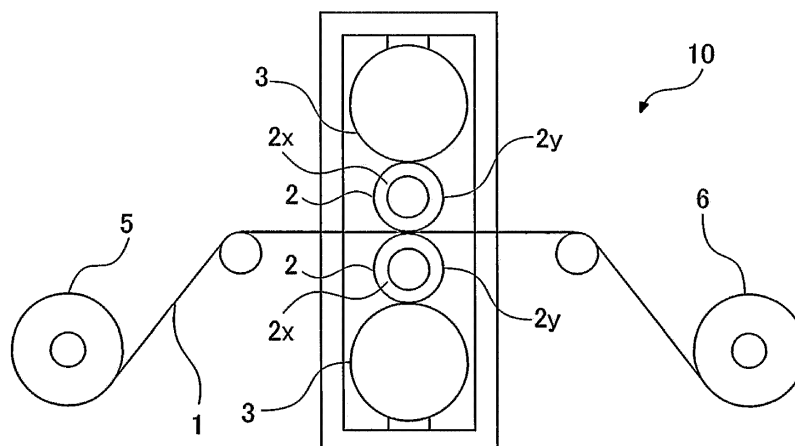
(54) **WORK ROLL FOR ROLLING, ROLLING MACHINE EQUIPPED WITH SAME, AND ROLLING METHOD**

(57) [Object] To provide a rolling work roll with which it is possible to effectively perform rolling with stable product qualities even with an increase in rolling distance when skin pass rolling is performed on a high-strength steel strip, and a skin pass rolling method using the roll.

[Solution] A rolling work roll 2 includes a roll barrel

2x made of a cemented carbide having a Young's modulus of 450 GPa or higher, and a recess and projection layer 2y which is formed on the roll barrel 2x, which has an arithmetic average roughness Ra of 2.0 μm to 10.0 μm, and which contains granular chromium.

FIG. 1



Description

Technical Field

5 **[0001]** The present invention relates to a rolling work roll for rolling a high-strength steel strip and a rolling mill having the roll, and a rolling method.

Background Art

10 **[0002]** Conventionally, a skin pass rolling mill, with which soft reduction is performed on a steel strip with a rolling reduction ratio of, for example, 1% or less, is known. A steel strip is homogeneously elongated by the skin pass rolling mill so that the shape of the steel strip is corrected to obtain predetermined flatness. Moreover, the properties of the steel strip, such as mechanical properties, such as yield point elongation, tensile strength, and elongation, and surface roughness, are improved by performing skin pass rolling. Nowadays, due to a trend toward a high value-added steel strip, there is an increasing demand for a hard steel strip typified by a high-tensile-strength steel strip. Particularly in the case of a high-tensile-strength steel sheet having a tensile strength of a 980 MPa or higher, a significantly high rolling load is necessary to achieve an elongation ratio required for shape correction.

15 **[0003]** Therefore, various kinds of skin pass rolling methods for a high-tensile-strength steel sheet have been proposed to date (for example, refer to Patent Literature 1 to Patent Literature 3). Patent Literature 1 discloses a method in which skin pass rolling is performed by using a work roll having a surface average roughness Ra of 3.0 μm to 10.0 μm . Patent Literature 2 discloses a method utilizing a cemented carbide which consists of tungsten carbide (WC) and cobalt (Co) and whose surface layer has a Young's modulus of 500 GPa or higher as a roll material. Patent Literature 3 discloses a method in which skin pass rolling is performed by using a roll whose surface layer has a Young's modulus of 450 GPa or higher and whose surface roughness Ra is 1 μm or more and 10 μm or less.

Citation List

Patent Literature

30 **[0004]**

PTL 1: Japanese Unexamined Patent Application Publication No. 2008-173684

PTL 2: Japanese Unexamined Patent Application Publication No. 2017-119303

PTL 3: Japanese Unexamined Patent Application Publication No. 2011-189404

Summary of Invention

Technical Problem

40 **[0005]** In the case of Patent Literature 1 to Patent Literature 3 described above, the surface of a rolling work roll has a predetermined arithmetic average roughness which is obtained by performing dull texturing process. Usually, it is considered that, when dull texturing process is performed, for example, a shot blasting processing method or a discharge dull texturing process is used as described in Patent Literature 1. However, in the case of such a method, there is a risk of a problem such as a decrease in surface roughness due to abrasion or crack growth with an increase in rolling distance. In such a case, there is a problem in that it is necessary, for example, to repair or replace a rolling work roll due to the above problem occurring in the rolling work roll, which makes it difficult to stably perform a rolling operation.

45 **[0006]** An object of the present invention is to provide a rolling work roll with which it is possible to stably perform a rolling operation when skin pass rolling is performed on a high-strength steel strip and a rolling mill having the roll, and a rolling method.

Solution to Problem

[0007] The present invention has the following features to solve the problems described above.

55 [1] A rolling work roll including a roll barrel made of a cemented carbide having a Young's modulus of 450 GPa or higher, and a recess and projection layer which is formed on an outer peripheral surface of the roll barrel, which has an arithmetic average roughness of 2.0 μm to 10.0 μm , and which contains granular chromium.

[2] The rolling work roll according to item [1], in which the recess and projection layer is formed by performing

chromium plating and thereby precipitating granular chromium.

[3] A skin pass rolling mill having at least one rolling stand having the rolling work roll according to item [1] or [2].

[4] A skin pass rolling method including performing skin pass rolling with an elongation ratio of 0.2% or more by using at least one stand of the skin pass rolling mill having the rolling work roll according to item [3]. Advantageous

Effects of Invention

[0008] By using the rolling work roll and a rolling mill having the roll, and the rolling method according to the present invention described above, since a recess and projection layer which is formed on the outer peripheral surface of the roll barrel, which has an arithmetic average roughness of 2.0 μm to 10.0 μm , and which contains granular chromium is used, it is possible to inhibit problems occurring in a work roll such as a decrease in surface roughness due to abrasion and crack growth, even when there is an increase in rolling distance, which makes it possible to stably perform a rolling operation.

Brief Description of Drawings

[0009]

[Fig. 1] Fig. 1 is a schematic diagram illustrating a preferable embodiment of a rolling mill 10 having rolling work rolls 2 according to the present invention.

[Fig. 2] Fig. 2 is an enlarged surface photograph illustrating an example of a recess and projection layer 2y of the rolling work roll 2 in the skin pass rolling mill in Fig. 1.

[Fig. 3] Fig. 3 is a graph illustrating an example of the variation in surface roughness with respect to a plating time.

[Fig. 4] Fig. 4 is a graph illustrating an example of the variation in rolling load with respect to an elongation ratio in the case of conventional examples 1 and 2, comparative example 1, and example 1 in Table 1.

[Fig. 5] Fig. 5 is an enlarged surface photograph illustrating the surface of a cemented carbide which has been subjected to conventional discharge dull texturing process.

[Fig. 6] Fig. 6 is a graph illustrating the variation in surface roughness of the rolls with respect to a rolling distance of the work rolls when a rolling experiment is performed by using the rolling work rolls given in Table 3. Description of Embodiments

[0010] Hereafter, the embodiments of the present invention will be described. Fig. 1 is a schematic diagram illustrating a preferable embodiment of a rolling mill 10 having rolling work rolls according to the present invention. The rolling mill 10 in Fig. 1 is used for performing skin pass rolling on a wide steel strip having a tensile strength of, for example, 980 MPa or higher. The skin pass rolling mill 10 has a pair of rolling work rolls 2 and back-up rolls 3, each of which supports a corresponding one of the rolling work rolls 2. A payoff reel 5 is arranged upstream of the skin pass rolling mill 10, and a tension reel 6 is arranged downstream of the skin pass rolling mill 10. Thereby, while a steel strip 1 is subjected to tension by using the payoff reel 5 and the tension reel 6, the steel strip 1 is subjected to rolling reduction by using the rolling work rolls 2 so that the steel strip 1 is subjected to a predetermined elongation ratio of, for example, 0.2% to 1.0%. However, bridle rolls may be arranged upstream or downstream of the skin pass rolling mill 10 to apply tension to the steel strip 1.

[0011] The rolling work roll 2 has a structure in which a roll barrel 2x made of a cemented carbide is fixed to, for example, a shaft. The roll barrel 2x is made of a cemented carbide which has a Young's modulus of 450 GPa or higher and which contains, for example, by mass%, 86% tungsten carbide (WC) and a balance of cobalt (Co). In the case where Young's modulus is 450 GPa or higher, it is possible to prevent an increase in the contact arc length in a roll bite between the rolling work rolls 2 and the steel strip 1 due to the flattening deformation of the rolling work rolls 2 and to thereby prevent an excessive increase in rolling load acting on the rolling work rolls 2, even when skin pass rolling is performed on a high-strength steel sheet.

[0012] In the part corresponding to the roll barrel surface of the roll barrel 2x, a recess and projection layer 2y containing granular Cr is formed. In the recess and projection layer 2y, the recessed and projected shape including the surface morphology is formed by performing chromium plating and thereby precipitating granular chromium so that an arithmetic average roughness (hereinafter, referred to as "surface roughness") Ra of 2.0 μm to 10.0 μm is obtained. Here, it is preferable that the recess and projection layer 2y be formed at least on the roll barrel surface of the roll barrel 2x, but the recess and projection layer 2y may be formed throughout the outer peripheral surface of the roll barrel 2x.

[0013] Incidentally, in the case where skin pass rolling is performed with a rolling reduction ratio of 1.0% or less by using rolling work rolls 2 having high surface roughness Ra, there is a decrease in rolling load. This is considered to be because, since the rough recessed and projected shape of the rolling work rolls 2 is printed onto the surface of the steel strip, there is a marked phenomenon (elongation effect), in which the portions of the steel strip that are pushed out by the indentation of the projected parts of the work roll contribute to elongation.

[0014] In the case where the surface roughness R_a is less than $2.0\ \mu\text{m}$, when plastic deformation is induced by indenting the recessed and projected shape of the rolling work rolls 2 onto the surface of the steel sheet, since the adjacent recessed portions and projected portions interfere with each other, there is an insufficient elongation effect. In particular, it is preferable that the surface roughness R_a of the rolling work rolls 2 be $3.0\ \mu\text{m}$ or more to realize the elongation effect. Here, under a skin pass rolling condition in which a low elongation ratio of about 0.2% is applied, in the case where the surface roughness R_a of the work rolls is more than $4.0\ \mu\text{m}$, the distance between adjacent projected portions is so large that there is almost no plastic deformation interference. Therefore, to effectively realize the elongation effect and to thereby decrease the rolling load, it is preferable that the surface roughness R_a of the recess and projection layer 2y be more than $4.0\ \mu\text{m}$.

[0015] On the other hand, it is preferable that the surface roughness R_a of the recess and projection layer 2y not be more than $10.0\ \mu\text{m}$ from the viewpoint of not only extreme difficulty in stably forming large surface roughness on the rolling work rolls 2 in industrial processes but also roll service life. Therefore, it is preferable that the surface roughness R_a of the work rolls be $10.0\ \mu\text{m}$ or less.

[0016] This recess and projection layer 2y is formed of granular Cr, which is precipitated by performing a chromium plating treatment. First, as a pretreatment for a chromium plating treatment which is performed to improve the adhesiveness between the surface of the roll barrel 2x and a chromium coating layer, after the surface of the roll barrel 2x is polished so that the surface roughness R_a thereof is, for example, $0.2\ \mu\text{m}$, the polished surface is subjected to, for example, a sand blasting treatment so as to have a surface roughness R_a of $0.8\ \mu\text{m}$. Subsequently, the surface of the roll barrel 2x is subjected to a washing treatment followed by a chromium plating treatment.

[0017] The chromium plating treatment is performed, for example, under the conditions of a low plating bath temperature of 50°C or lower and a high current density of $60\ \text{A/dm}^2$ or more. With this, it is possible to increase the diameter of Cr crystal grains which are precipitated on the surface of the roll barrel 2x. That is, in the case of an industrially used hard chromium coating layer, the morphology and hardness of Cr precipitated vary depending on electroplating conditions (plating bath temperature, current density, and plating time). Generally, in the case of bright plating, which is widely used, the treatment is performed under the conditions of a plating bath temperature of about 50°C to 60°C and a current density of about $40\ \text{A/dm}^2$ to $60\ \text{A/dm}^2$ to obtain a flat and smooth surface. On the other hand, in the case of the recess and projection layer 2y described above, since it is necessary that a recessed and projected shape be formed to obtain the predetermined surface roughness R_a , plating is performed under the conditions of a low plating bath temperature of 50°C or lower and a high current density of $60\ \text{A/dm}^2$ or more to precipitate granular Cr.

[0018] Fig. 2 is an enlarged surface photograph illustrating an example of the recess and projection layer of the rolling work roll in the skin pass rolling mill in Fig. 1. In the case of the recess and projection layer 2y in Fig. 2, chromium plating was performed in a plating solution containing chromic acid (CrO_3) and sulfuric acid (H_2SO_4) under the conditions of a plating bath temperature of 37°C , a current density of $120\ \text{A/dm}^2$, and a plating time of 150 min. Thereby, a granular recess and projection layer 2y was formed on the surface of the roll barrel 2x through the precipitation of Cr. At this time, when the surface roughness R_a was determined by using a contact-type roughness meter, the surface roughness R_a was $3.9\ \mu\text{m}$. In addition, no crack or the like occurred in the recess and projection layer 2y.

[0019] The surface roughness R_a of the recess and projection layer 2y is controlled by controlling plating time. Fig. 3 is a graph illustrating the variation in surface roughness R_a after the plating when only a plating time is varied under the plating conditions for Fig. 2. Since there is an increase in surface roughness R_a with an increase in plating time, it is possible to achieve desired surface roughness R_a by controlling the plating conditions. Here, it is preferable that the average grain diameter of Cr precipitated on the roll surface by performing chromium plating be $50\ \mu\text{m}$ or more. This is for the purpose of effectively realizing an elongation effect due to the indentation of the recessed and projected shape onto the steel sheet surface. By increasing the average grain diameter of Cr, since it is possible to increase the distance between adjacent recessed portions and projected portions, it is possible to inhibit interference between the adjacent recessed portions and projected portions when plastic deformation is induced by the indentation of the recessed and projected shape onto the surface of the steel sheet.

<Rolling load experiment>

[0020] A rolling experiment was performed to clarify the effect of decreasing a rolling load due to rolling work rolls 2 having the recess and projection layer 2y described above. Here, in the experiment, a high-tensile-strength steel sheet having a thickness of $0.215\ \text{mm}$, a width of $20\ \text{mm}$, a length of $200\ \text{mm}$, and a yield stress of $1500\ \text{MPa}$ was used as a sample material. In addition, a 4-high rolling mill having work rolls having a diameter of $\phi 70\ \text{mm}$ was used as a skin pass rolling mill 10 to perform cut-sheet rolling without tension under a dry condition without a lubricant. This was a 1/7-scale model experiment for a roll diameter and a sheet thickness used in practical rolling performed on a high-tensile-strength steel sheet for an automobile.

[0021] By performing rolling with various roll gaps by using 4 kinds of work rolls given in Table 1 as work rolls, an investigation was conducted regarding the relationship between the rolling load and the elongation ratio, which was

derived from a change in the length of the steel sheet before and after rolling.

[Table 1]

No.	Roll Barrel Material	Roll Barrel Young's Modulus (GPa)	Dull Texturing Process	Arithmetic Average Roughness Ra (μm)	Note
1	2%-Cr Steel	206	Bright Polishing	0.2	Comparative Example 1
2	2%-Cr Steel	206	Discharge Dull Texturing Process	3.0	Conventional Example 1
3	Cemented carbide (86% WC)	503	Bright Polishing	0.2	Conventional Example 2
4	Cemented carbide (86% WC)	503	Cr Plating for Dull Texturing Process	2.5	Example 1

[0022] In Table 1, in the case of comparative example 1 (No. 1), the roll barrel 2x was made of 2%-Cr steel having a Young's modulus of 206 GPa, and the surface thereof was subjected to grindstone polishing to obtain a surface roughness Ra of 0.2 μm . In the case of conventional example 1 (No. 2), the roll barrel 2x was made of 2%-Cr steel, and the surface thereof was subjected to discharge dull texturing process to obtain a surface roughness Ra of 3.0 μm . In the case of conventional example 2 (No. 3), the roll barrel 2x was made of a cemented carbide containing, by mass%, 86% tungsten carbide (WC) and a balance of cobalt and having a Young's modulus of 503 GPa. The surface thereof was subjected to grindstone polishing to obtain a surface roughness Ra of 0.2 μm . In the case of example 1 (No. 4), the roll barrel 2x was made of the same cemented carbide as in the case of conventional example 2 (No. 3), and the surface thereof was subjected to chromium plating for dull texturing process to form the recess and projection layer 2y having a surface roughness Ra of 2.5 μm .

[0023] Fig. 4 is a graph illustrating the variation in load per unit width with respect to an elongation ratio in the case of conventional examples 1 and 2, comparative example 1, and example 1. As illustrated in Fig. 4, on the basis of a comparison between comparative example 1 (No. 1) and conventional example 1 (No. 2), whose work rolls are both made of 2%-Cr steel, in terms of load per unit width for the same elongation ratio, the load per unit width of conventional example 1 (No. 2), in which the surface roughness is large, is lower than that of comparative example 1, which indicates that the elongation effect due to the indentation of the projected portions of the surface of the rolling work rolls onto the surface of the steel sheet was realized.

[0024] On the other hand, in the case of conventional example 2 (No. 3) where the roll barrel 2x was made of a cemented carbide, the load per unit width was lower than that for the same elongation in the case of conventional example 1 (No. 2), which indicates that the effect of inhibiting flattening deformation due to an increase in the Young's modulus of the rolls was realized. In the case of example 1 (No. 4), the load per unit width was lower than that in the case of conventional example 2 (No. 3) as a result of the realization of not only the elongation effect due to the indentation of the projected portions of the surface of the rolling work rolls but also the effect of inhibiting flattening deformation of the rolls, which indicates that the effect of decreasing the rolling load was large.

[0025] Incidentally, skin pass rolling is usually performed with an elongation ratio of about 0.2% to 1.0%, and there is an improvement in the flatness of a steel strip with an increase in elongation ratio within such a range of the elongation ratio. Here, the term "elongation ratio" denotes the ratio of a change in the length in the longitudinal direction of a steel strip before and after rolling to the original length. In the case where the elongation ratio is 0.2% or more, since it is possible to sufficiently correct the shape of a steel strip, even if it is a high-strength cold-rolled steel strip, it is possible to achieve generally good flatness on the front and back surface sides of the steel strip. In addition, it is preferable that the elongation ratio applied to a steel strip be 0.5% or less to control the rolling load acting on the work rolls and the skin pass rolling mill 10 to be within the load capacity of the skin pass rolling mill.

<Continuous operation experiment>

[0026] To evaluate the soundness of a roll surface when continuous operation is performed, a rolling contact test in which two rolling work rolls were pressed against each other with a constant surface pressure while rotating was performed in the case of comparative example 2 and example 2 described below. In the case of comparative example 2, the roll barrel 2x was made of a cemented carbide (having a Young's modulus of 503 GPa) containing, by mass%, 86% tungsten

carbide (WC) and a balance of cobalt, and the surface thereof was subjected to direct discharge dull texturing process to obtain a surface roughness Ra of 3.0 μm .

[0027] Fig. 5 is an enlarged surface photograph illustrating the surface of the recess and projection layer in the case where the roll barrel 2x made of a cemented carbide was subjected to dull texturing process by performing direct discharge processing as in the case of comparative example 2. As illustrated in Fig. 5, a crack CK occurred on the surface due to the impact when discharge processing was performed. Here, it is known that a crack CK occurs in the case where a material such as a cemented carbide which contains mainly ceramics that is a brittle material is subjected to discharge processing.

[0028] On the other hand, in the case of example 2, the roll barrel 2x was made of a cemented carbide (having a Young's modulus of 503 GPa) containing, by mass%, 86% tungsten carbide (WC) and a balance of cobalt, and the surface thereof was subjected to chromium plating to form the recess and projection layer 2y having a surface roughness Ra of 3.0 μm .

[0029] As a continuous operation experiment, by using a 4-high rolling mill having work rolls having a diameter of $\phi 70$ mm and a barrel length of 40 mm, the work rolls were rotated at a velocity of 50 mpm while the work rolls were pressed against each other with a load of 1.8 tons. The pressure between the work rolls has a maximum value in an elastic contact region between the work rolls which are pressed against each other, and the maximum pressure in this experiment was set to be 1011 MPa. This value is at the comparable level of the surface pressure applied to the work rolls of a skin pass rolling mill used in a continuous annealing line in practical use or the like. In the experiment, the rolling contact test was performed for various durations, and the surface of the work roll was observed after each time by using a microscope to check whether or not, for example, cracking, fracturing, or separation occurred in the surface of the work roll. The experimental results are summarized in Table 2.

[Table 2]

No.	0 min (Initial Stage)	30 min	60 min	120 min	240 min	300 min	Note
1	Crack Observed	Crack Observed	Crack Observed	Crack Observed	Crack Observed	Separation Occurred	Comparative Example 2
2	Sound	Sound	Sound	Sound	Sound	Sound	Example 2

[0030] In Table 2, in the case of comparative example 2 where the predetermined surface roughness Ra was obtained by performing discharge dull texturing process, it was clarified that a crack occurred on the surface of the work roll at the initial stage (refer to Fig. 5). In the case where rolling is performed by using a rolling work roll having such a crack, the crack grows with an increase in rolling contact time due to stress applied to the rolling work roll during rolling. As a result, after a rolling contact time of 300 min, fracturing and separation occurred in the roll surface. On the other hand, in the case where the rolling work roll which had been subjected to chromium plating for dull texturing process was used, for example, no cracking or fracturing was observed (as denoted by the term "sound" in Table 2), which indicates that it is possible to stably use such a roll.

<Continuous operation experiment 2>

[0031] In addition, to evaluate roll roughness retainability when continuous operation is performed, a rolling experiment was performed by using 4 kinds of rolling work rolls, as in comparative example 3, comparative example 4, example 3, and example 4 given in Table 3 below.

[Table 3]

No.	Roll Barrel Material	Roll Barrel Young's Modulus (GPa)	Dull Texturing Process	Arithmetic Surface Roughness Ra (μm)	Note
1	2%-Cr Steel	206	Discharge Dull Texturing Process	4.5	Comparative Example 3
2	Cemented carbide (80% Co)	450	Discharge Dull Texturing Process	4.5	Comparative Example 4

(continued)

No.	Roll Barrel Material	Roll Barrel Young's Modulus (GPa)	Dull Texturing Process	Arithmetic Surface Roughness Ra (μm)	Note
3	Cemented carbide (80% WC)	450	Cr Plating for Dull Texturing Process	4.5	Example 3
4	Cemented carbide (80% WC)	450	Cr Plating for Dull Texturing Process + Hard Cr Plating	4.5	Example 4

[0032] In the case of comparative example 3, the roll barrel 2x was made of 2%-Cr steel having a Young's modulus of 206 GPa, and the surface thereof was subjected to discharge dull texturing process to obtain a surface roughness Ra of 4.5 μm . In the case of comparative example 4, the roll barrel 2x was made of a cemented carbide (having a Young's modulus of 450 GPa) containing, by mass%, 80% tungsten carbide (WC) and a balance of cobalt, and the surface thereof was subjected to discharge dull texturing process to obtain a surface roughness Ra of 4.5 μm without performing chromium plating.

[0033] On the other hand, in the case of example 3, the roll barrel 2x was made of a cemented carbide (having a Young's modulus of 450 GPa) containing, by mass%, 80% tungsten carbide (WC) and a balance of cobalt, and the surface thereof was subjected to chromium plating to form the recess and projection layer 2y having a surface roughness of 4.5 μm . At this time, the average grain diameter of Cr precipitated was 60 μm .

[0034] In the case of example 4, after granular Cr was precipitated on the roll surface by using the same method as that in the case of example 3 described above, a hard chromium coating layer having a thickness of 1 μm was further formed on the roll surface under alternate plating conditions. Here, the reason why the additional hard chromium coating layer was formed under alternate plating conditions is as follows. In the case where a recessed and projected shape is formed by precipitating granular Cr on the surface of the roll under the plating conditions of a low plating bath temperature of 50°C or lower and a high current density of 60 A/dm², the Vickers hardness of the chromium coating layer is about 700 to 900. On the other hand, in the case where an ordinary hard chromium coating layer is formed under the conditions of a plating bath temperature of about 50°C to 60°C and a current density of about 40 A/dm² to 60 A/dm², the Vickers hardness of the hard chromium coating layer is about 900 to 1100. Here, the reason why a hard chromium coating layer was further formed under alternate plating conditions after granular Cr had been precipitated on the roll surface by using the same method as that in the case of example 3 is because, since a significantly hard coating layer is formed on the outermost surface of the rolling work roll, there is a further improvement in abrasion resistance.

[0035] The reason why the thickness of the additional hard chromium coating layer is set to be 1 μm as described above is because, in the case where the thickness is equal to or more than that, since there is a decrease in the height difference in the recessed and projected shape formed by grains in the early stage, there is a decreased elongation effect when skin pass rolling is performed. That is, by forming an additional thin hard chromium coating layer on the granular chromium precipitated in the early stage of the plating process, it is possible to increase the hardness of the surface of the coating layer without changing the roughness pattern formed of granular chromium. Here, for such a reason, it is preferable that the thickness of the additional hard chromium coating layer be 0.5 μm to 10 μm .

[0036] Then, by using the 4 kinds of rolling work rolls having a roll diameter of $\phi 70$ mm and barrel length of 40 mm given in Table 3 as rolling work rolls of a 4-high rolling mill, a continuous coil rolling experiment was performed with tension being applied. A high-tensile-strength steel sheet having a thickness of 0.215 mm, a width of 20 mm, and a yield stress of 1500 MPa was used as a material to be rolled. Coil rolling was performed with a tension of 100 MPa being applied to the inlet and exit sides of the mill, under a dry condition without a lubricant, and with a rolling load per unit width of 0.2 ton/mm. At this time, the variation in the surface roughness of each of the rolls with respect to a rolling distance was determined.

[0037] Fig. 6 is a graph illustrating the variation in surface roughness with respect to a rolling distance when a rolling experiment is performed by using the rolling work rolls given in Table 3. As illustrated in Fig. 6, it is clarified that, in the case of comparative example 3 where 2%-Cr steel roll was subjected to discharge dull texturing process, there is a significant decrease in roughness with an increase in rolling distance. In the case of comparative example 4 where a cemented carbide was subjected to direct discharge dull texturing process to obtain high roughness, since the hardness of the cemented carbide is significantly high, the best roll roughness retainability with respect to the rolling distance was achieved. However, since fracturing occurred in the roll surface after a rolling distance of 1.67 km, it was difficult to further continue rolling. This is because, as described above, in the case where a cemented carbide is subjected to

direct discharge processing, a crack occurs and grows due to stress applied when rolling is performed, which makes it difficult to use such a roll in practical rolling.

[0038] On the other hand, it is clarified that, in the case of example 3 and example 4 of the present invention, although there is a decrease in roughness due to early-stage abrasion, the roll roughness retainability with respect to the rolling distance thereafter was far better than that in the case of comparative example 3. In particular, it is clarified that, in the case of example 4 where a thin hard chromium coating layer is formed on the surface, excellent roll roughness retainability was achieved.

[0039] According to the embodiments described above, by using the recess and projection layer 2y which is formed on the outer peripheral surface of the roll barrel 2x, which has a surface roughness Ra of 2.0 μm to 10.0 μm , and which is formed of granular chromium, since it is possible to inhibit a decrease in surface roughness Ra due to abrasion and a deterioration in work roll properties due to, for example, the occurrence of a crack, even when there is an increase in rolling distance, it is possible to stably perform skin pass rolling. In particular, it is possible to decrease a rolling load by only changing the raw material of the rolling work roll 2 used for the skin pass rolling mill 10 and a method for processing the surface thereof without causing any change in equipment such as a roll radius, which has a significant effect on the industry.

[0040] In particular, in the case of the kind of a high-tensile-strength steel sheet that is manufactured by using a continuous annealing method in which quenching and tempering are performed, the shape (flatness) of the steel strip is likely to be deteriorated due to thermal stress generated when quenching is performed and due to transformation stress generated when transformation occurs in a metallographic structure. It is not possible to eliminate such a shape defect of a steel strip even if shape correction of the steel strip is tried when cold rolling is performed before annealing is performed. Therefore, it is necessary to perform shape correction by performing skin pass rolling on the steel strip after annealing has been performed.

[0041] In addition, a high-tensile-strength steel sheet having a tensile strength of 980 MPa or higher is used as a raw material for automobile parts, which are obtained by performing press forming on the steel sheet. To increase oil retainability when press forming is performed, it is necessary that the surface of the steel sheet is subjected to dull texturing process (recessed and projected processing). In the dull texturing process of the surface of the steel strip 1, the surface condition of the steel strip is controlled by printing the recessed and projected shape of the rolling work rolls 2 of the skin pass rolling mill 10 onto the surface of the steel sheet, where the recessed and projected shape of the rolling work rolls are ordinarily prepared by performing dull texturing process in advance.

[0042] The elongation ratio is controlled by applying tension to the steel strip and by setting a work roll gap when skin pass rolling is performed. To achieve a larger elongation ratio, a tension and a rolling load higher than conventional ones are necessary. In particular, in the case where skin pass rolling is performed on a high-tensile-strength steel strip having a tensile strength of higher than 980 MPa, since the deformation resistance of the steel strip is significantly high, further larger rolling load is necessary.

[0043] Since an often-used ordinary skin pass rolling mill is not designed under the assumption that skin pass rolling is performed on such a high-tensile-strength steel strip, the rolling load exceeds the load capacity of the skin pass rolling mill when skin pass rolling is performed on a high-tensile-strength steel strip. Here, it is considered that rolling load is decreased by changing the structure of a skin pass rolling mill from a 4-high type to a 6-high type or the like and thereby decreasing a work roll diameter. However there is a problem in that, since this requires extensive equipment modification, there is an increase in cost.

[0044] As described above, particularly in the case of a high-tensile-strength steel strip where shape correction is required, there may be a problem of an increase in rolling load to the extent that the capacity of an existing skin pass rolling mill is exceeded. Therefore, it is a fact that shape correction is performed by using a leveler or the like in subsequent processes now, which results in a problem of an increase in manufacturing costs due to additional processes and of a protracted delivery period.

[0045] Therefore, processing is performed on the surfaces of the rolling work rolls 2 to achieve a surface roughness Ra of 2.0 μm to 10.0 μm so that it is possible to realize the desired rolling effect while decreasing the rolling load. In addition, the roll barrel 2x is made of a cemented carbide having a Young's modulus of 450 GPa or higher. With this, even when rolling is performed on a high-tensile-strength steel sheet having a tensile strength of 980 MPa or higher, it is possible to achieve the desired load per unit width without increasing roll diameter.

[0046] On the other hand, when discharge dull texturing process is performed to achieve a surface roughness Ra of 2.0 μm to 10.0 μm as described above, since there is a decrease in the surface roughness Ra of the rolling work rolls due to abrasion with an increase in rolling distance, there may be a case where the effect of maintaining low rolling load is not realized.

[0047] Therefore, the recess and projection layer 2y is formed of granular chromium, which is precipitated by performing a chromium plating. With this, it is possible not only to form the recess and projection layer 2y without a crack but also to achieve a Vickers hardness with which the abrasion is less likely to occur in the surface, even when rolling is repeated. In addition, in the case where the recess and projection layer 2y is formed of granular chromium, since the projected

portion of the granular chromium has a spherical shape, there is a decreased local stress concentration during rolling, which results in an increase in abrasion resistance compared with the case of an ordinary chromium coating layer. As a result, since there is a decrease in the frequency of the repair and replacement of the work rolls, it is possible to stably operate a rolling process.

[0048] In addition, by using at least one rolling mill 10 described above to perform skin pass rolling with an elongation ratio of 0.2% or more, since it is possible to sufficiently perform shape correction on a steel sheet, even when it is a high-strength cold-rolled steel strip, it is generally possible to achieve good flatness on the front and back surface sides of the steel strip.

[0049] The embodiments of the present invention are not limited to the embodiments described above, and it is possible to make various changes to the embodiments. In addition, although an example in which a technique of the present invention is applied to a stand-alone skin pass rolling mill illustrated in Fig. 4 has been described, the technique of the present invention may be applied to rolling mills which are installed as in-line rolling mills in continuous process lines such as a continuous annealing line (CAL) and a continuous galvanizing line (CGL).

Reference Signs List

[0050]

- 1 steel strip
- 2 rolling work roll
- 2x roll barrel
- 2y recess and projection layer
- 3 back-up roll
- 5 payoff reel
- 6 tension reel
- 10 skin pass rolling mill
- CK crack
- Ra arithmetic average roughness (surface roughness)

Claims

1. A rolling work roll comprising:

a roll barrel made of a cemented carbide having a Young's modulus of 450 GPa or higher; and
a recess and projection layer which is formed on an outer peripheral surface of the roll barrel, which has an arithmetic average roughness of 2.0 μm to 10.0 μm , and which contains granular chromium.

2. The rolling work roll according to Claim 1, wherein the recess and projection layer is formed by performing chromium plating and thereby precipitating granular chromium.

3. A rolling mill comprising the rolling work roll according to Claim 1 or 2.

4. A rolling method comprising performing skin pass rolling with an elongation ratio of 0.2% or more by using at least one stand of the rolling mill according to Claim 3.

FIG. 1

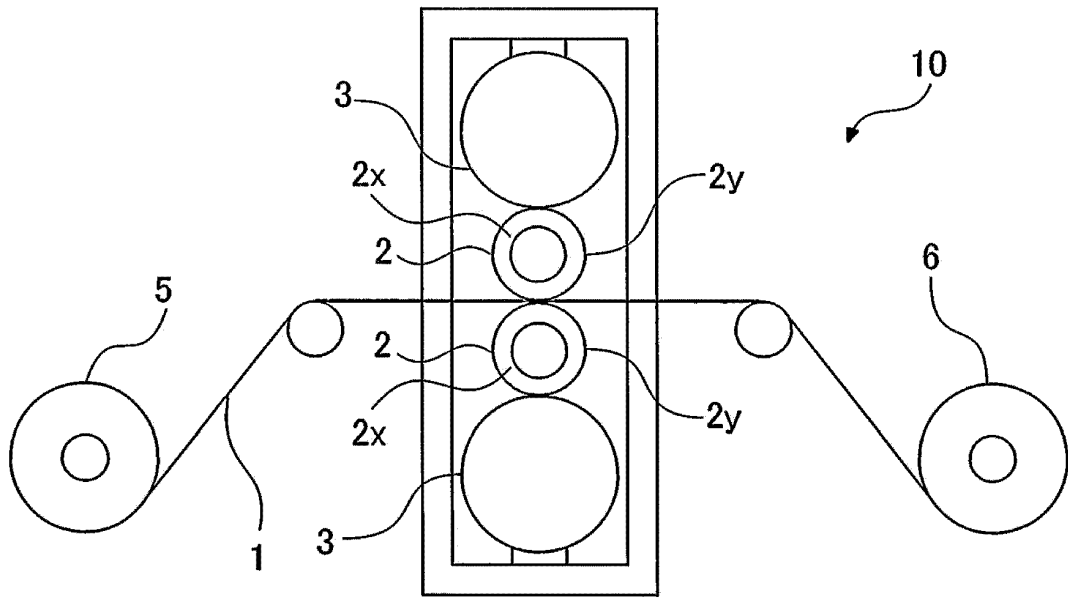


FIG. 2

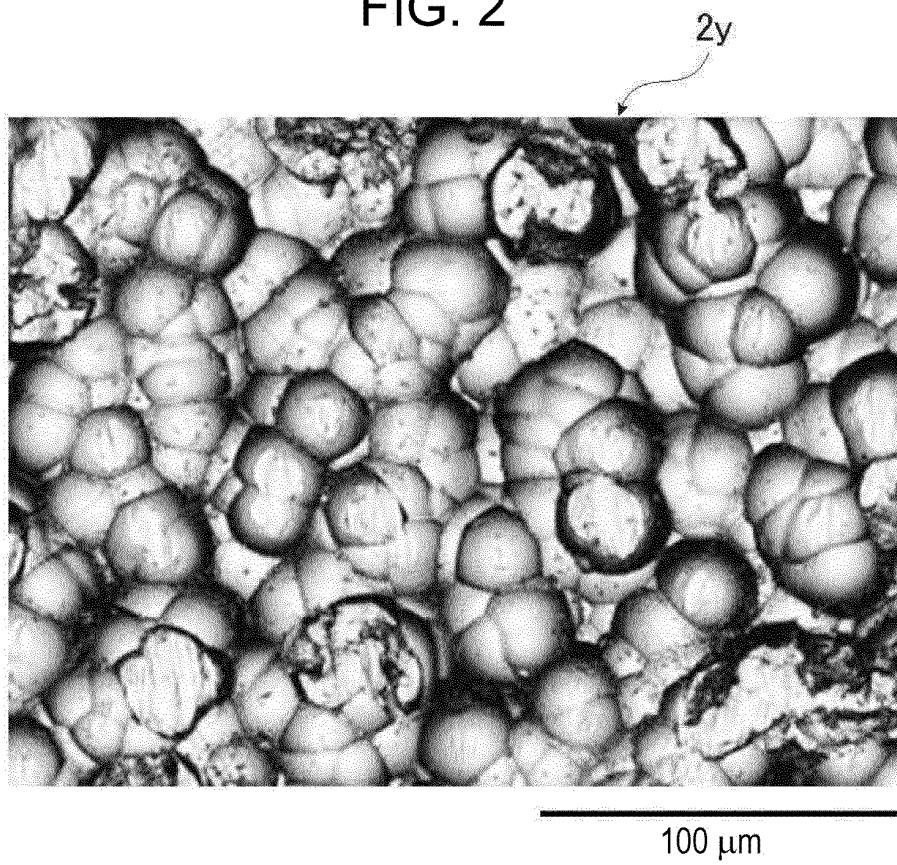


FIG. 3

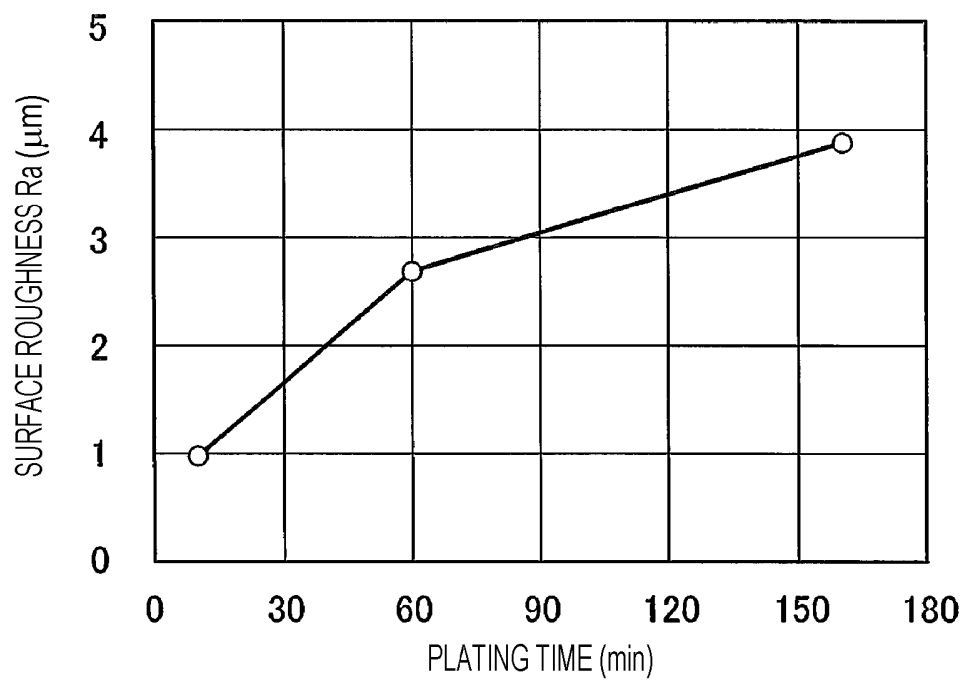


FIG. 4

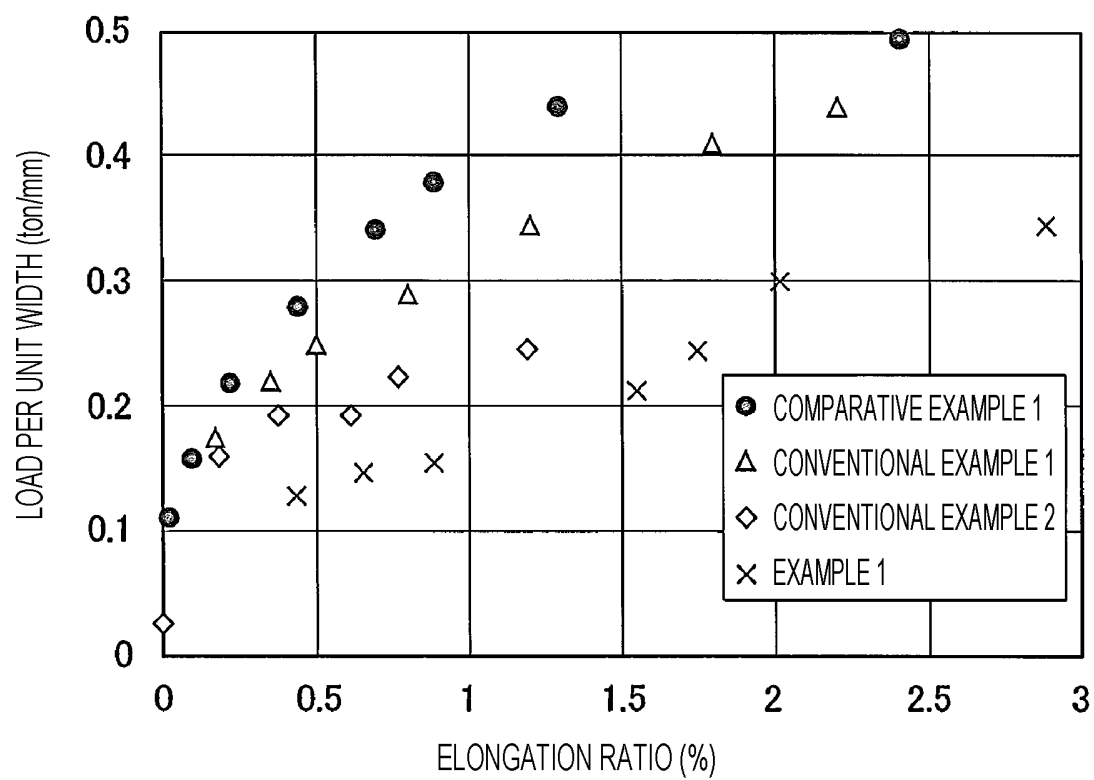


FIG. 5

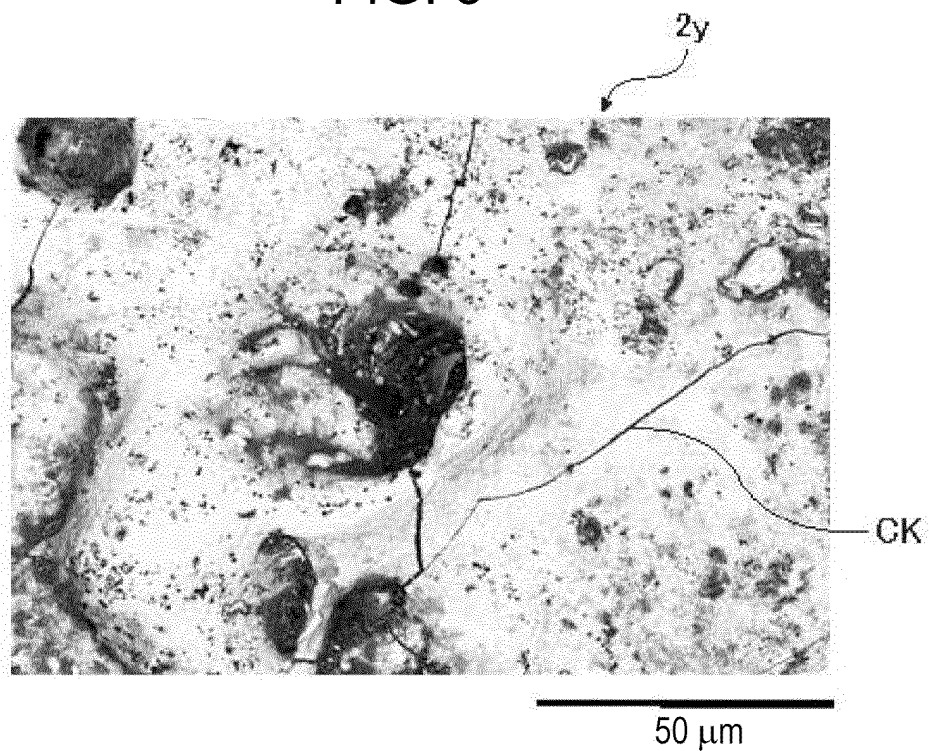
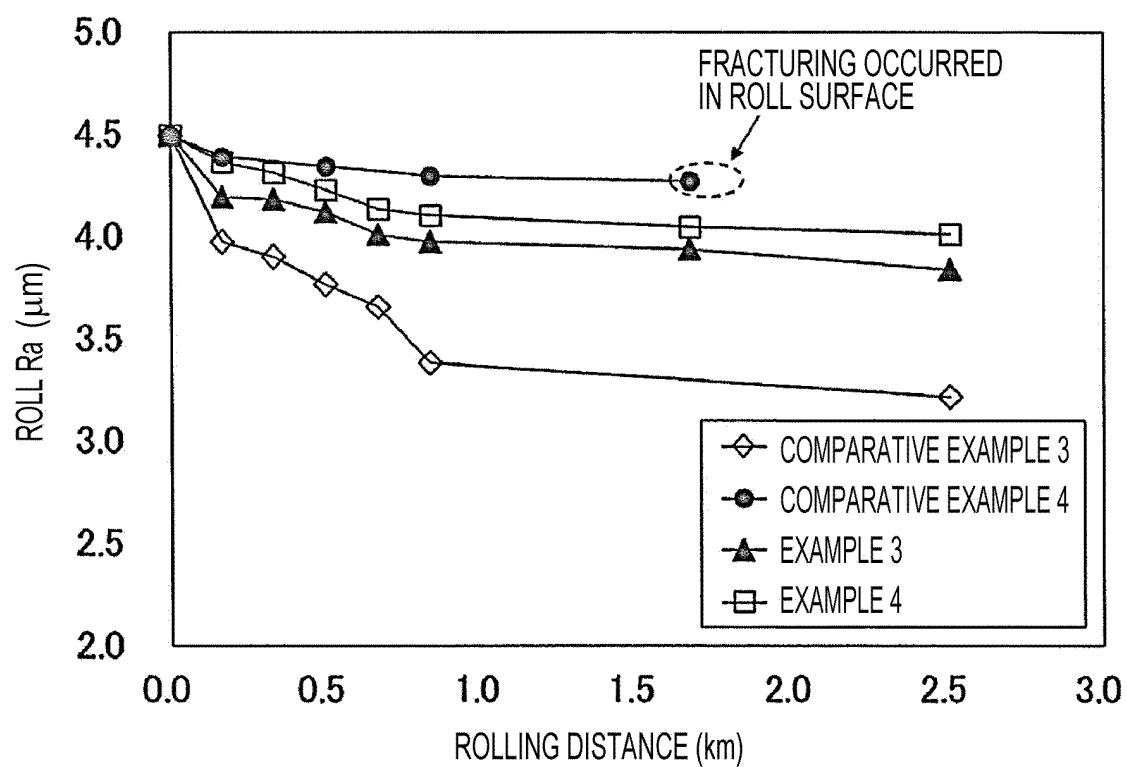


FIG. 6



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2019/041848

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. B21B27/00 (2006.01) i, B21B1/22 (2006.01) i, C25D7/00 (2006.01) i,
C25D7/04 (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. B21B27/00-35/14, B21B1/22, C25D7/00, C25D7/04

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	1971-2019
Registered utility model specifications of Japan	1996-2019
Published registered utility model applications of Japan	1994-2019

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 61-129205 A (SUMITOMO METAL INDUSTRIES, LTD.) 17 June 1986, entire text (Family: none)	1-4
A	JP 1-258806 A (SUMITOMO METAL INDUSTRIES, LTD.) 16 October 1989, entire text (Family: none)	1-4
A	JP 7-1021 A (NISSHIN STEEL CO., LTD.) 06 January 1995, entire text (Family: none)	1-4
A	JP 52-107243 A (KOBAYASHI, Yoshinobu) 08 September 1977, entire text (Family: none)	1-4

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

* Special categories of cited documents:	"I" 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
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"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
29.11.2019

Date of mailing of the international search report
10.12.2019

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Tokyo 100-8915, Japan

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2019/041848

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2017-100149 A (JFE STEEL CORPORATION) 08 June 2017, entire text (Family: none)	1-4
A	CN 202052762 U (WUHU HENGDA SHEETING METAL CO., LTD.) 03 November 2011, entire text (Family: none)	1-4

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

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2008173684 A [0004]
- JP 2017119303 A [0004]
- JP 2011189404 A [0004]