



(11)

EP 4 378 603 A1

(12)

EUROPEAN PATENT APPLICATION
published in accordance with Art. 153(4) EPC

(43) Date of publication:

05.06.2024 Bulletin 2024/23

(21) Application number: **22869693.6**

(22) Date of filing: **21.07.2022**

(51) International Patent Classification (IPC):

B21B 45/02 (2006.01) **B21B 45/06** (2006.01)
B21C 51/00 (2006.01) **C21D 1/00** (2006.01)
B21B 38/00 (2006.01)

(52) Cooperative Patent Classification (CPC):

B21B 38/00; B21B 45/02; B21B 45/06;
B21C 51/00; C21D 1/00

(86) International application number:

PCT/JP2022/028414

(87) International publication number:

WO 2023/042545 (23.03.2023 Gazette 2023/12)

(84) Designated Contracting States:

AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR

Designated Extension States:

BA ME

Designated Validation States:

KH MA MD TN

(30) Priority: **16.09.2021 JP 2021150947**

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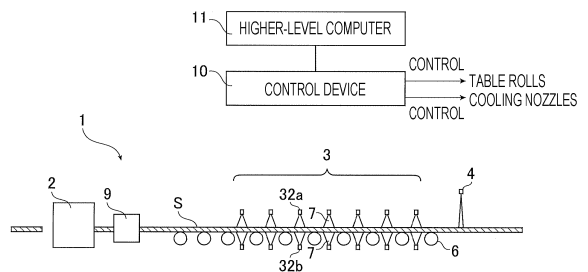
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(54) **MANUFACTURING METHOD AND MANUFACTURING EQUIPMENT FOR THICK STEEL PLATE**

(57) An object is to provide a manufacturing facility and a method for manufacturing in which, without additionally providing an ancillary facility and consuming excessive energy, a film boiling state is maintained until a temperature as low as possible is reached.

A method for manufacturing a steel plate in which water-cooling is performed on the steel plate. In the method, a water-cooling device that includes a plurality of combinations of at least one pair of upper and lower cooling water injection nozzles arranged in a traveling direction of the steel plate is used. In the method, an injection speed of cooling water of the cooling water injection nozzles is higher than or equal to 0.4 m/s and lower than or equal to 30 m/s to perform the water-cooling on the steel plate.

FIG. 1



Description

Technical Field

5 **[0001]** The present invention relates to a method for manufacturing a steel plate and a steel plate manufacturing facility.

Background Art

10 **[0002]** Nowadays, as the size of building structures increases, strength of used steel materials is required to be increased. At the same time, from the viewpoint of safety, it is also required for the steel materials to have high allowable stress and a reduced yield ratio, which is a ratio of the yield strength to the tensile strength. When the yield ratio is reduced, even in the case where stress greater than the yield point is applied, stress and uniform elongation allowed without causing fracture increase, and accordingly, a steel material having a good plastic deformation capacity preferable to building structures is obtained.

15 **[0003]** A basic technical concept of the manufacture of low yield ratio steel is as follows. A composite microstructure of a ferrite phase and a bainite or a martensite phase is made so as to keep the yield stress low with the soft ferrite phase. High tensile strength is obtained with the hard bainite or martensite phase so as to reduce the yield ratio.

20 **[0004]** In general, a composite microstructure can be obtained by controlling mainly cooling, in particular, accelerated cooling immediately after hot rolling. More specifically, the accelerated cooling is divided into two stages, that is, mild cooling at an earlier stage and rapid cooling at a later stage, and a soft ferrite phase is sufficiently grown in the mild cooling at the earlier stage. Then, the hard bainite or martensite phase is obtained through the rapid cooling at the later stage so as to obtain a composite microstructure that realizes a low yield ratio.

25 **[0005]** For example, Patent Literature 1 discloses a method for manufacturing a steel pipe with a low yield ratio and a high weldability configured with a composite microstructure including a soft ferrite phase and a hard bainite or martensite phase. According to the method for manufacturing the welded steel pipe with a low yield ratio described in Patent Literature 1, the accelerated cooling is performed by dividing the accelerated cooling into two stages, that is, an earlier stage cooling in which mild cooling is performed until the temperature of a steel sheet immediately after hot rolling reduces to about 600 °C and a later stage cooling in which, after the earlier stage cooling, rapid cooling is performed until a coiling temperature is reached. The above-described Patent Literature 1 describes that the soft ferrite phase is sufficiently grown through the mild cooling at the earlier stage and the hard bainite or martensite phase can be obtained through the rapid cooling at the later stage.

30 **[0006]** Also according to Patent Literature 1, in a state in which the steel pipe is obtained by welding the steel sheet, when the wall thickness of the steel pipe is t and the outer diameter of the steel pipe is D , a welded steel pipe with a low yield ratio that satisfies the following relationships can be obtained: yield ratio $\leq 80\%$ when $t/D \leq 2$; yield ratio $\leq 85\%$ when $2 < t/D \leq 3$; and yield ratio $\leq 88\%$ when $t/D > 3$. As a specific cooling rate to precipitate the soft ferrite phase, Patent Literature 2 discloses a technique with which mild cooling is performed at a cooling rate of 5 to 15 °C/s on a steel plate having a thickness of 25 mm.

35 **[0007]** An example of a history of a steel plate surface temperature in a water-cooling process for a high-temperature steel plate is illustrated in Fig. 2. As illustrated in Fig. 2, at an initial stage of water-cooling, cooling is performed in a film boiling state in which a steam film exists between the steel plate and water. Since the water and the steel plate are not in direct contact with each other in the film boiling state, the heat transfer coefficient being an indicator of cooling capacity is low, and reduction of the surface temperature is mild.

40 **[0008]** However, when the surface temperature reaches about 700 to 500 °C, maintaining of the steam film between the water and the steel plate becomes difficult, and cooling is performed in a transition boiling state in which the water and the steel plate are partly in contact with each other. Once the contact between the water and the steel plate occurs, flowing of the water near the steel plate becomes violent due to evaporation of the water having been brought into contact with the steel plate. As a result, the heat transfer coefficient increases sharply and the surface temperature reduces sharply. Then, while the high heat transfer coefficient is maintained, the state transitions to the nucleate boiling state in which the contact between the steel plate and the water steadily occurs, and the surface temperature reduces sharply to about the water temperature.

45 **[0009]** When, as is the case with the technique described in Patent Literature 1 or Patent Literature 2, the steel plate is subjected to mild cooling until the temperature becomes about 600 °C, the steel plate is preferably cooled in the film boiling state in which the heat transfer coefficient is low. However, as described above, when the steel plate surface temperature reaches about 700 to 500 °C, the film boiling state transitions to the nucleate boiling state in which the heat transfer coefficient is high. Once the film boiling state transitions to the nucleate boiling state, the steel plate surface temperature reduces sharply and the cooling rate becomes excessive. Thus, a steel plate having desired characteristics cannot be manufactured. In addition, when the transition to the nucleate boiling state occurs in part in the steel plate, the predetermined characteristics cannot be made only in this part. Thus, uniform characteristics throughout the steel

plate cannot be obtained. Accordingly, when the steel plate is water-cooled in the film boiling state, it is important to control the temperature at which the film boiling state transitions to the nucleate boiling state so as to stably maintain the film boiling state.

[0010] From the schematic diagram of the water-cooling process illustrated in Fig. 2, it can be understood that the film boiling state sometime inevitably transitions to the nucleate boiling state. According to, for example, Non Patent Literature 1, it is thought that the lower limit value, that is, the lower limit value of the transition temperature can be organized with a nucleus spontaneous generation temperature. That is, it is contended that a necessary condition for generation of an evaporation nucleus in the cooling medium and transition to the film boiling state is that an interface temperature between a cooling medium and the steel plate exceeds the nucleus spontaneous generation temperature of the cooling medium.

[0011] When the thermal conductivity is λ , the diffusivity of heat is α , and the temperature is T , a parameter of the cooling medium is represented by a subscript w, and a parameter of the steel plate is represented by a subscript s, the interface temperature T_b between the cooling medium and the steel plate is given by expression 1.

[Math. 1]

$$T_b = (T_w(\lambda_w/\sqrt{\alpha_w}) + T_s(\lambda_s/\sqrt{\alpha_s})/(\lambda_w/\sqrt{\alpha_w} + \lambda_s/\sqrt{\alpha_s}) \quad \text{Expression 1}$$

[0012] When the cooling medium is water, T_b is defined to be about 300 °C. Thus, when a water temperature T_w is 30 °C, a steel plate temperature T_s at which the nucleus spontaneous generation occurs in the water in the case where carbon steel is water-cooled is about 330 to 350 °C. Thus, the film boiling state is physically maintained only until the temperature reaches 330 to 350 °C at the lowest, and the film boiling cooling is required to be stopped at a steel plate surface layer temperature higher than or equal to that temperature. Accordingly, it is to be noted that the cooling water is to be injected to the steel plate before the temperature of the front/back layer of the steel plate becomes 350 °C at the lowest.

[0013] When the required cooling rate is high, it is possible to obtain such a rate by increasing the transition temperature and performing the nucleate boiling state and a natural cooling state intermittently. For example, according to Patent Literature 3, cooling nozzles arranged in a row in the traveling direction of a steel plate are separated by pinch rolls, and rapid cooling of a nucleate boiling state in which water of a high flow rate is injected and a natural cooling state in which water is not injected are alternately provided. Thus, it is stated that stable cooling at a surface layer cooling rate of higher than or equal to 30 °C/s can be performed.

[0014] As a cooling without boiling transition as described above, injection of a gas (for example, air) to the steel plate is conceivable. However, in general, a cooling capacity of gas by forced convection is lower than a film boiling cooling capacity of water-cooling by an order, and accordingly, it is required that a gas be injected at high speed to obtain a target cooling rate. Thus, it is required that the injection is performed after the gas has been compressed with a compressor or the like. However, in view of an increase in the manufacturing cost due to power consumption of the compressor, this is not a preferred solution.

[0015] In view of the above-described situation, in manufacturing a product of a low yield ratio steel for which division into the mild cooling at the earlier stage and the rapid cooling at the later stage is performed so as to made the composite microstructure, the mild cooling at the earlier stage is preferably performed as water-cooling in the film boiling state in which the heat transfer coefficient is low. However, when the steel plate surface temperature reaches 700 to 500 °C, the film boiling state transitions to the nucleate boiling state in which the heat transfer coefficient is high. Thus, it is important to stably maintain the film boiling state until a low temperature is reached.

[0016] As a technique of stably maintaining the film boiling state until a low temperature is reached, for example, Patent Literature 4 discloses a technique in which the temperature of cooling water is set to be high so as to reduce the transition temperature to the nucleate boiling state. Also, Patent Literature 5 discloses a technique in which steam is added to water to reduce the transition temperature to the nucleate boiling state and increase the heat transfer coefficient in the film boiling state.

Citation List

Patent Literature

[0017]

PTL 1: Japanese Unexamined Patent Application Publication No. 10-17980

PTL 2: Japanese Unexamined Patent Application Publication No. 2005-313223

PTL 3: Japanese Unexamined Patent Application Publication No. 2005-154841

PTL 4: Japanese Unexamined Patent Application Publication No. 58-71339

PTL 5: Japanese Unexamined Patent Application Publication No. 10-300301

Non Patent Literature

[0018] NPL 1: Power Reactor and Nuclear Fuel Development Corporation, "Vapor Explosion Phenomenon related to Safety Assessment of Nuclear Reactor", February 1980.

Summary of Invention

Technical Problem

[0019] However, according to the technique described in Patent Literature 2, a specific method for maintaining the mild cooling of 5 to 15 °C/s until a sufficiently low temperature is reached is not described and the lower limit is 600 °C. In view of variations in processes and components, it is thought that mild cooling down to a lower temperature of lower than or equal to 600 °C is required. Thus, it is thought that, with the technique described in Patent Literature 2, the characteristics of manufactured product is not stable.

[0020] According to the technique disclosed in Patent Literature 3, the cooling performed by alternately providing the rapid cooling in the nucleate boiling state and the natural cooling state is limited to a condition in which the surface layer cooling rate is higher than or equal to 30 °C/s. Thus, the technique in Patent Literature 3 cannot be applied to a low cooling rate process in which the surface layer cooling rate is lower than 30 °C/s such as a process in which the cooling rate is 5 to 15 °C/s required by the technique in Patent Literature 5.

[0021] In order to increase the water temperature as in Patent Literature 4 as a technique for reducing the transition temperature, there are problems in that ancillary facilities such as a heater and the like are required, and in addition, the manufacturing cost increases due to running cost of ancillary facilities. Furthermore, when the cooling water for the steel plate is recycled, the cooling water temperature varies depending on extraction efficiency of the steel plate, and accordingly, it becomes more difficult to manage the cooling water temperature.

[0022] Furthermore, also when steam is used as in Patent Literature 5, ancillary facilities to generate steam are required. In addition, it is required to newly provide valves and headers for controlling the amount of steam. This leads to an increase in facility cost and degradation of maintainability due to an increase in management items. In addition, in each of both the related-art techniques, the transition temperature from the film boiling to the nucleate boiling state is reduced by increasing the cooling water temperature. However, excessively consuming energy for increasing the water temperature is not preferable in view of energy saving.

[0023] Meanwhile, it is known that, in general, the cooling capacity and the water flow density of the cooling water in a cooling zone correlate with each other. Accordingly, when the steel plate is cooled at a desired cooling rate, the cooling capacity is adjusted by controlling the water flow density of the cooling water in the cooling zone. Meanwhile, the water flow density of the cooling water in the cooling zone also correlates with the steel plate surface layer temperature at the moment at which the film boiling state transitions to the nucleate boiling state (hereinafter, referred to as a transition temperature). Thus, according to the related art, when there is a desired cooling rate, the water flow density cannot be reduced for the purpose of reducing the transition temperature, and it is impossible to reduce only the transition temperature independently.

[0024] Accordingly, although the physical lower limit temperature has been proposed to allow the maintaining of the cooling in the film boiling state as described in Non Patent Literature 1, no method is known to reduce a boiling transition temperature with the parameter of the water flow density fixed.

[0025] The present invention is made in view of the above-described situation, and an object of the present invention is to provide a method for manufacturing a steel plate and a steel plate manufacturing facility in which, without additionally providing an ancillary facility and consuming excessive energy, a film boiling state is maintained until a low temperature is reached.

Solution to Problem

[0026] The configurations of the gist of the present invention that solves the above-described problems are as follows.

[1] A method for manufacturing a steel plate in which water-cooling is performed on the steel plate. In the method, a water-cooling device that includes a plurality of combinations of at least one pair of upper and lower cooling water injection nozzles arranged in a traveling direction of the steel plate is used. In the method, an injection speed of cooling water of the cooling water injection nozzles is higher than or equal to 0.4 m/s and lower than or equal to 30 m/s to perform the water-cooling on the steel plate.

[2] In the method for manufacturing a steel plate according to [1], a surface layer cooling rate of the steel plate in the water-cooling device is higher than or equal to 0.4 °C/s and lower than or equal to 29 °C/s.

[3] In the method for manufacturing a steel plate according to [1] or [2], descaling is performed on the steel plate before the water-cooling.

[4] In the method for manufacturing a steel plate according to any one of [1] to [3], an oxide scale removing process and heating are performed on the steel plate before the water-cooling.

[5] In the method for manufacturing a steel plate according to any one of [1] to [4], a temperature of either or both of upper and lower surfaces of the steel plate is measured after the water-cooling.

[6] In the method for manufacturing a steel plate according to any one of [2] to [5], the surface layer cooling rate is controlled by controlling an amount of the cooling water injected from the cooling water injection nozzles.

[7] In the method for manufacturing a steel plate according to any one of [1] to [6], a cooling stop temperature of the steel plate is controlled by controlling a number of the cooling water injection nozzles and a line speed of the steel plate, and the cooling stop temperature represented by a surface layer temperature of the steel plate is greater than or equal to 350 °C.

[8] A steel plate manufacturing facility that performs water-cooling on the steel plate. The facility includes a water-cooling device that includes a plurality of combinations of at least one pair of upper and lower cooling water injection nozzles arranged in a traveling direction of the steel plate, and a control device that controls an injection speed of cooling water injected from the cooling water injection nozzles to be higher than or equal to 0.4 m/s and lower than or equal to 30 m/s.

[9] In the steel plate manufacturing facility according to [8], the control device controls a surface layer cooling rate of the steel plate in the water-cooling device to be higher than or equal to 0.4 °C/s and lower than or equal to 29 °C/s.

[10] The steel plate manufacturing facility according to [8] or [9] further includes a descaling device disposed on an entry side of the water-cooling device.

[11] The steel plate manufacturing facility according to any one of [8] to [10] further includes a thermometer that is disposed on an exit side of the water-cooling device and measures a temperature of either or both of upper and lower surfaces of the steel plate.

[12] In the steel plate manufacturing facility according to any one of [8] to [11], the control device further controls an amount of the cooling water injected from the cooling water injection nozzles.

[13] In the steel plate manufacturing facility according to any one of [8] to [12], the control device controls a number of cooling water injection nozzles and a line speed of the steel plate.

Advantageous Effects of Invention

[0027] According to the steel plate manufacturing facility and the method for manufacturing a steel plate, in water-cooling the steel plate at a significantly low cooling rate, the film boiling state can be stably maintained until the low temperature is reached. When the film boiling state is stably maintained until the low temperature is reached, the steel plate that is entirely uniform in terms of characteristics can be manufactured.

Brief Description of Drawings

[0028]

[Fig. 1] Fig. 1 is a schematic diagram illustrating a configuration of a heat treatment facility for a steel plate.

[Fig. 2] Fig. 2 is a graph illustrating a history of a steel plate surface temperature in a water-cooling process.

[Fig. 3] Fig. 3 is a graph illustrating the relationship between an injection speed of cooling water and a transition temperature of the steel plate.

[Fig. 4] Fig. 4 is a block diagram illustrating a configuration of a control device and so forth.

[Fig. 5] Fig. 5 is a schematic diagram illustrating the configuration of the heat treatment facility including a draining roll.

[Fig. 6] Fig. 6 is a schematic diagram illustrating the configuration of the heat treatment facility including a draining purge nozzle.

[Fig. 7] Fig. 7 is a schematic diagram illustrating the configuration of the heat treatment facility including the draining roll and the draining purge nozzle.

[Fig. 8] Fig. 8 is a schematic diagram illustrating the configuration of the heat treatment facility including large flow-rate cooling-water injection nozzles on an entry side and an exit side of a water-cooling device.

[Fig. 9] Fig. 9 is a schematic diagram illustrating the configuration of the heat treatment facility including the large flow-rate cooling-water injection nozzles inside the water-cooling device.

[Fig. 10] Fig. 10 is a schematic diagram illustrating the configuration of the heat treatment facility for the steel plate according to an example.

[Fig. 11] Fig. 11 is a graph illustrating the relationship between a water flow density and a cooling rate in cooling zones.

[Fig. 12] Fig. 12 is a graph illustrating the relationship between the water flow density and the injection speed in the cooling zones.

5 Description of Embodiments

[0029] Hereinafter, an embodiment of the present invention is described with reference to the drawings. The embodiment described below exemplifies apparatuses and methods for embodying the technical concept of the present invention, and the technical concept of the present invention does not identify the shape, structure, disposition, and so forth of elements as the following embodiment. Furthermore, the drawings are schematically illustrated. Accordingly, it is noted that the relationships, the ratios, and the like between the thickness and the planar dimensions are different from actual relationships, ratios, and the like. The dimensional relationships and the ratios of some parts included in the drawings are also different from each other between the drawings.

[0030] Fig. 1 is a schematic diagram illustrating a configuration of a heat treatment facility for a steel plate as an embodiment of the present invention. As illustrated in Fig. 1, a heat treatment facility 1 for a steel plate as the embodiment of the present invention is an off-line facility and includes, as its main elements, an oxide scale removing device (not illustrated) that performs an oxide scale removing process on a steel plate S, a heating furnace 2 that heats the steel plate S to a predetermined temperature, a water-cooling device 3 that cools the steel plate S heated by the heating furnace 2, a descaling device 9 that performs descaling on the steel plate S between the heating furnace 2 and the water-cooling device 3, a thermometer 4 that measures the temperature of the steel plate S on an exit side of the water-cooling device 3, and a control device 10 that controls operation of the water-cooling device 3. Furthermore, the heat treatment facility 1 corresponds to a "steel plate manufacturing facility" according to the present invention.

[0031] The steel plate S that has been hot rolled to a predetermined thickness (for example, 30 mm) and a predetermined width (for example, 2000 mm) in a hot rolling line at a different position from the position of the heat treatment facility 1 and has been cooled to a temperature about the room temperature is charged into the heating furnace 2. The steel plate S is heated to a predetermined temperature (for example, 910 °C) in the heating furnace 2. The steel plate S extracted from the heating furnace 2 is cooled with the water-cooling device 3 while being traveled with a plurality of table rolls 6 installed on the exit side of the heating furnace 2.

[0032] In general, in an off-line heat treatment facility, the steel plate is traveled at about a constant speed from the extraction from the heating furnace 2 to the end of the cooling with the water-cooling device 3. Thus, the difference in cooling start temperature between a leading end and a trailing end of the steel plate is small. That is, when the heating temperature of the steel plate is defined as T_0 , the distance from the heating furnace 2 to the water-cooling device 3 is defined as L_0 , and a line speed of the steel plate is defined as V_0 , a leading end portion of the steel plate is extracted at the temperature T_0 and cooled after a radiational cooling time L_0/V_0 has passed. Since the distance L_0 from the heating furnace 2 to the water-cooling device 3 is small in the off-line heat treatment facility, the temperature of a trailing end portion of the steel plate is maintained at the temperature T_0 in the heating furnace 2 even when the leading end portion of the steel plate has been extracted from the heating furnace 2 and reaches an entry side of the water-cooling device 3. Accordingly, since the trailing end portion of the steel plate is also extracted at the temperature T_0 similarly to the leading end portion and cooled after the radiational cooling time L_0/V_0 has passed, the cooling start temperature can be maintained constant through the entire length of the steel plate. As described above, regarding the steel plate the temperature of which is likely to reduce through the radiational cooling, a feature of the off-line heat treatment facility is that the off-line heat treatment facility has the advantage in manufacturing a steel plate that is entirely uniform in terms of material properties.

[0033] However, the present invention can be applied to an on-line heat treatment facility. In this case, the object is a heat treatment facility for a steel plate that includes a heating facility that heats the steel plate, a rolling facility that rolls the steel plate heated with the heating facility, and a water-cooling device that cools the steel plate rolled to a predetermined thickness with the rolling facility. Also in this case, similarly to the off-line heat treatment facility, the steel plate is in a state in which the steel plate has been heated to a high temperature on an entry side of the water-cooling device. Meanwhile, in the on-line heat treatment facility, the radiational cooling time from a time immediately after rolling to a time of starting cooling is greater in the trailing end portion than in the leading end portion of the steel plate. Accordingly, when the length of the steel plate is defined as L and the line speed of the steel plate is defined as v , the radiational cooling time differs between the trailing end portion and the leading end portion by time L/v . Accordingly, even when the temperature of the steel plate after the rolling is uniform, the trailing end portion is subjected to radiational cooling excessively by the difference in radiational cooling time. Thus, the cooling start temperature differs between the leading end portion and the trailing end portion, and thereby a steel plate that is entirely uniform in terms of the characteristics cannot be obtained. For this reason, as will be described later, the temperature of the steel plate is preferably predicted with the control device 10, and, accordingly operation conditions of the water-cooling device 3 are preferably varied along the longitudinal positions of the steel plate S.

[0034] In the heating furnace 2, heating is preferably performed in a nonoxidated atmosphere (for example, nitrogen atmosphere). The reason for this is that, as will be described later, the transition temperature is influenced by the thickness of an oxide scale, and as the thickness of the oxide scale increases, ease of transition from a film boiling state to a nucleate boiling state increases. In so doing, the oxygen concentration in the heating furnace 2 is preferably controlled to be smaller than or equal to 1% (percent by volume).

[0035] The water-cooling device 3 included is a water-cooling device 3 that water-cools the steel plate S under predetermined conditions. In the water-cooling device 3, upper cooling water injection nozzles 32a and lower cooling water injection nozzles 32b form a plurality of upper-lower pairs with respect to the traveling direction of the steel plate S and are arranged at predetermined intervals in the traveling direction of the steel plate S. Cooling water 7 is injected from the cooling water injection nozzles 32 (upper cooling water injection nozzles 32a and the lower cooling water injection nozzles 32b) toward the steel plate S. That is, the water-cooling device 3 includes a plurality of combinations of at least one pair of upper and lower cooling water injection nozzles arranged in the traveling direction of the steel plate S. Furthermore, the steel plate S is cooled while being traveled with the table rolls 6 arranged at predetermined intervals in the traveling direction of the steel plate S. A cooling section in which a single pair of the cooling water injection nozzles 32a and 32b are regarded as one unit is referred to as a cooling zone, and cooling zones are counted with the unit of "zone". Although a total of seven zones of the cooling zones are illustrated in Fig. 1, the effect of the present invention is not impaired when the number of zones is other than seven.

[0036] Operation parameters of the water-cooling device 3 include the amount of water (the amount of cooling water) of the cooling water 7 injected from the pair of cooling water injection nozzles 32a and 32b and the line speed of the steel plate S traveled with the table rolls 6. As the amount of cooling water increases, a cooling rate and a temperature reduction amount of the steel plate S can increase. Meanwhile, as the line speed of the steel plate S reduces, the temperature reduction amount of the steel plate S can increase. Furthermore, when these parameters are combined with each other, a cooling stop temperature and the cooling rate can be controlled as the cooling conditions for obtaining the desired material properties.

[0037] As the operation parameter of the water-cooling device 3, a cooling zone-by-cooling zone balance of the amount of cooling water (for example, the amount of cooling water is increased in a cooling zone on the upstream side and reduced in a cooling zone on the downstream side, or the like) may be set. The reason for this is that the cooling rate can be controlled in accordance with temperature regions of the steel plate S. Furthermore, the number of cooling zones in which the cooling water is injected may be set. The reason for this is that the cooling stop temperature can be controlled while the cooling rate is made to be the same by the number of cooling zones to be used.

[0038] Preferably, the cooling rate is variable in accordance with the material properties in various manners. Preferably, the surface layer cooling rate is smaller than or equal to 29 °C/s from the viewpoint of obtaining a soft ferrite phase. More preferably the steel plate S is cooled at a surface layer cooling rate of smaller than or equal to 15 °C/s and, even more preferably smaller than or equal to 10 °C/s. Furthermore, when the surface layer cooling rate is smaller than 0.4 °C/s, the cooling rate is almost the same as that of the radiational cooling, and production efficiency degrades. Accordingly, the surface layer cooling rate is preferably greater than or equal to 0.4 °C/s.

[0039] Referring to a schematic diagram of a water-cooling process illustrated in Fig. 2, the fact that the film boiling state inevitably transitions to the nucleate boiling state sometime is as described above, and a lower limit of the temperature thereafter is from about 330 to 350 °C. Accordingly, it is sufficient that injection of the cooling water 7 to the steel plate S be stopped preferably at a temperature of the front or back surface of the steel plate S of higher than or equal to 350 °C, and more preferably at a temperature of the front/back surface of the steel plate S of higher than or equal to 400 °C.

[0040] Furthermore, when the relationship between an injection speed V of the cooling water and the transition temperature T_t illustrated in Fig. 3 is formulated, it is represented by expression 2 below.

[Math. 2]

$$T_t = 400 \times V^{0.1371} \quad (\text{Expression 2})$$

[0041] When substituting the injection speed for stably injecting the cooling water, which will be described later, in expression 2, T_t = 350 °C with V = 0.4 m/s, and T_t = 400 °C with V = 0.9 m/s. Also from these results, it is sufficient that injection of the cooling water 7 to the steel plate S be stopped preferably at a temperature of the front/back surface of the steel plate S of higher than or equal to 350 °C, and more preferably at a temperature of the front/back surface of the steel plate S of higher than or equal to 400 °C.

[0042] After the cooling has been stopped at the above-described temperature, the nucleate boiling state is likely to be established. Accordingly, rapid cooling by using the nucleate boiling state is preferably performed with a known technique. In order to maintain the cooling by using the nucleate boiling, the minimum water flow density in the cooling zone is preferably greater than or equal to 300 L/(m²·min). Furthermore, it is to be considered that rapid cooling by using

the nucleate boiling is reliably performed even on the steel plate at high temperature and of a large heat content. Thus, the minimum water flow density in the cooling zone is more preferably greater than or equal to 1000 L/(m²·min), even more preferably, greater than or equal to 1500 L/(m²·min), and most preferably, greater than or equal to 2000 L/(m²·min). In contrast, when the water flow density is greater than 4000 L/(m²·min) in the cooling zone, the cooling rate is rarely varied even in a case where the water flow density increases. From this, since the water flow density of greater than 4000 L/(m²·min) in the cooling zone is not preferable from the economic viewpoint such as power for the cooling water, it is better to set the maximum water flow density to a value smaller than or equal to 4000 L/(m²·min).

[0043] Furthermore, as a result of serious investigation by the inventors, it is clearly understood that, when the water flow density in the zone is the same, the transition temperature has a correlation with the injection speed of the cooling water injected from the cooling water injection nozzles. Fig. 3 illustrates the relationship between the injection speed of the cooling water injected from the cooling water injection nozzles and the transition temperature. It can be understood from the drawing that the injection speed of the cooling water and the transition temperature are in the positive relationship. In addition, it can also be understood from the drawing that, when mild cooling to 600 °C is performed as is the case with the technique described in Patent Literature 1, the injected cooling water is to be controlled to be smaller than or equal to 30 m/s. Accordingly, to stably maintain the film boiling state, the injection speed of the cooling water injected from the cooling water injection nozzles 32 is to be controlled to be smaller than or equal to 30 m/s, preferably smaller than or equal to 20 m/s, and more preferably smaller than or equal to 7 m/s. Furthermore, in order to stably inject the cooling water 7 injected from the cooling water injection nozzles 32, the injection speed is to be controlled to be greater than or equal to 0.4 m/s and preferably greater than or equal to 0.9 m/s.

[0044] As the cooling water injection nozzles 32, spray nozzles through which the cooling water can be uniformly injected at a predetermined injection speed can be used. In so doing, a type of nozzles that injects the cooling water while rotating the cooling water therein, specifically, full-cone spray type, full-cone square spray type, or the like is preferred. The reason for this is that the injection speed of the cooling water can be reduced by applying a rotation force to the water in the nozzle. As long as the injection speed can be sufficiently reduced, slit-type nozzles, multi-hole jet nozzles, or mist nozzles may be used. Preferably, the cooling nozzles are nozzles with which the cooling water flow density can be varied in a variety of manner in accordance with a target cooling rate.

[0045] The operation conditions of the cooling water injection nozzles 32 are not limited to the above description. That is, the cooling water injection nozzles 32 are set to be nozzles used for both cooling in the film boiling state and cooling in the nucleate boiling state, and different types of cooling including cooling in the film boiling state under the above-described conditions and cooling in the nucleate boiling state in which a large flow rate of the cooling water is to be injected are used depending on the desired material properties.

[0046] It is known that, in general, the transition temperature is influenced by an oxide scale generated on the front and back surfaces of the steel plate S. As the thickness of an oxide scale increases, the transition temperature tends to increase. Thus, in order to stably maintain the film boiling state, the oxide scale on the front and back surfaces of the steel plate S is preferably removed. Accordingly, the oxide scale generated on the front and back surfaces of the steel plate S is preferably removed with an oxide scale removing device before the steel plate S is charged into the heating furnace 2. As the oxide scale removing device, a shot blast device may be used to perform a shot blasting process on the steel plate S, thereby to remove the oxide scale on the front and back surfaces of the steel plate S. Alternatively, a pickling device may be used to perform a pickling process on the steel plate S, thereby to remove the oxide scale on the front and back surfaces of the steel plate S. Alternatively, a grinding device may be used to grind the steel plate S, thereby to remove the oxide scale on the front and back surfaces of the steel plate S.

[0047] Regarding the thickness of the oxide scale, the thickness of ordinary mill scale is about 10 to 50 μm. When the oxide scale removing process that has been described above as the specific examples is performed on the steel plate S having the oxide scale of such a thickness, the oxide scale can be reduced to have a thickness of smaller than 1 μm. Accordingly, the thickness of the oxide scale covering the front and back surfaces of the steel plate S to be charged into the heating furnace 2 is preferably smaller than 1 μm.

[0048] The oxide scale removing device is not necessarily disposed in the same line as the line of the heat treatment facility 1. An oxide scale removing device disposed in another line, another facility, or another factory may be used. The reason for this is that versatility of physical distribution of the steel plate S to be charged into the heating furnace 2 can be improved and production efficiency can be improved.

[0049] The steel plate S extracted from the heating furnace 2 is exposed to the atmosphere while remaining in the high-temperature state. Accordingly, the oxide scale is generated on the front and back surfaces of the steel plate S while the steel plate S is being traveled from the heating furnace 2 to the water-cooling device 3. Thus, preferably, the descaling device 9 is disposed between the heating furnace 2 and the water-cooling device 3 so as to perform descaling on the front and back surfaces of the steel plate S where the oxide scale has been generated.

[0050] Furthermore, both the descaling device 9 and the oxide scale removing device may be disposed. The scale can be uniformly and easily removed when the oxide scale generated on the steel plate S before the steel plate S is charged into the heating furnace 2 is removed with the oxide scale removing device and the oxide scale generated on

the steel plate S extracted from the heating furnace 2 is removed with the descaling device 9.

[0051] Regarding the thickness of the oxide scale, the thickness of ordinary mill scale is about 10 to 50 μm . When a descaling process is performed on the steel plate S having the oxide scale of such a thickness, the oxide scale can be reduced to have a thickness of smaller than 1 μm . Accordingly, the thickness of the oxide scale covering the front and back surfaces of the steel plate S entering the water-cooling device 3 is preferably smaller than 1 μm .

[0052] As described above, the steel plate S passes through the water-cooling device 3 so as to stop injection of the cooling water 7 to the steel plate S at a temperature of higher than or equal to 350 °C. Accordingly, with the thermometer 4 installed on the exit side of the water-cooling device 3, it can be checked whether the steel plate S can be cooled as intended by measuring a surface temperature of the steel plate S having been cooled with the water-cooling device 3. Furthermore, when calculation or heat transfer simulation are performed by using both heating temperature information and a temperature measurement result to calculate the cooling rate during water-cooling, whether the steel plate S can be cooled as intended can be checked. Furthermore, whether the steel plate S is uniformly cooled may be checked by measuring a in-plane temperature distribution of the steel plate S after the water-cooling.

[0053] The thermometer 4 is a device that measures the temperature of the steel plate S with, for example, a method in which the thermometer scans in the width direction of the steel plate S and a method in which a single thermometer or a plurality of thermometers are disposed in the width direction of the steel plate S. Furthermore, the thermometer 4 measures the temperature of either or both of the upper and lower surfaces of the steel plate.

[0054] Referring to Fig. 1, the thermometer 4 is installed on the exit side of the water-cooling device 3. However, the thermometer 4 may be installed in the water-cooling device 3 as long as the temperature of the steel plate having been cooled with the water-cooling device 3 can be measured. In so doing, a plurality of thermometers 4 may be installed so as to be arranged in the traveling direction of the steel plate S to measure the temperature of the steel plate S in each cooling zone. Furthermore, the thermometer 4 may be installed on the entry side of the water-cooling device 3 to measure the heating temperature or the cooling start temperature of the steel plate S. The reason for this is that accuracy of calculation of the cooling rate is improved when the temperature of the steel plate S is measured on the entry side of the water-cooling device 3.

[0055] The control device 10 includes a known information processing device such as a personal computer. The control device 10 acquires, from a higher-level computer 11, information on a target range of the cooling stop temperature required to obtain the desired material properties (a target cooling stop temperature) and a target range of the cooling rate (target cooling rate) in addition to size information of the steel plate S such as the heating temperature and the thickness. The control device 10 calculates operation conditions of the heat treatment facility 1 for realizing such conditions and determines operation parameters of devices of the water-cooling device 3.

[0056] According to the present embodiment, as illustrated in Fig. 4, the control device 10 executes a computer program, thereby to function as a water-cooling condition computation section 12. The water-cooling condition computation section 12 performs heat transfer calculation based on an internal model and determines the number of the cooling zones to be used, the amount of cooling water, and the line speed of the steel plate S so as to satisfy the target cooling stop temperature and the target cooling rate set as the cooling conditions. Command values of the amount of cooling water and the line speed of the steel plate S determined as described above are transmitted from a water-cooling operation condition output section 13 to the water-cooling device 3. In the water-cooling device 3, based on the command values of the amount of cooling water and the line speed of the steel plate S, the following values are determined: an operating pressure of cooling water pumps and the number of the cooling water pumps to be operated; the number of headers provided on the upstream side of the cooling water injection nozzles 32 and the valve opening of a flow regulating valve; and the rotation speed of a motor that drives the table rolls 6 are determined.

[0057] Next, a method for manufacturing the steel plate according to the present invention using the heat treatment facility 1 illustrated in Fig. 1 is described. First, in a different hot rolling line (not illustrated) from the heat treatment facility 1, the steel plate S is charged into the heating furnace 2. This steel plate S has been hot rolled in advance to a predetermined thickness (for example, 30 mm) and a predetermined width (for example, 2000 mm), and, after the temperature reached the room temperature, the oxide scale on this steel plate S has been removed by the oxide scale removing device. The steel plate S is heated to a predetermined temperature in the heating furnace 2.

[0058] Next, the steel plate S is extracted from the heating furnace 2 and cooled by using the water-cooling device 3 while being traveled by using the plurality of table rolls 6 installed on the exit side of the heating furnace 2. In this cooling step, the number of zones to be used and the amount of water are calculated by the control device 10 in accordance with the thickness and the target characteristics of the material. Here, as an example, the method for manufacturing in the case where the water is injected from all the zones illustrated in Fig. 1 is described.

[0059] First, regarding the steel plate S, the cooling water 7 is injected from the cooling water injection nozzles 32 disposed in seven upper-lower pairs to the steel plate S. The water flow density and the line speed of the steel plate S in the water-cooling device are set by the control device 10 so as to obtain the target characteristics of the steel plate and transmitted to the cooling water injection nozzles 32 and the table rolls 6 as the commands.

[0060] The steel plate S having undergone the cooling step is provided to a downstream step. When the steel plate

S extracted from the heating furnace 2 is caused to pass through the water-cooling device, the steel plate for which desired steel plate characteristics (for example, a yield ratio of smaller than or equal to 80%) is ensured can be manufactured.

[0061] Although the description of the embodiment according to the present invention has been made, the present invention is not limited to this, and various changes and improvements can be made. For example, as illustrated in Fig. 5, a draining roll 33 may be installed on the exit side of the water-cooling device 3 so as to remove the cooling water 7 remaining on the steel plate S. When the cooling water 7 remaining on the plate is removed, the desired cooling stop temperature, and in addition, characteristics can be more reliably obtained.

[0062] In order to obtain good draining performance, a pressing force of the draining roll 33 against the steel plate S is preferably greater than or equal to four tons, more preferably greater than or equal to six tons, and even more preferably greater than or equal to eight tons. When the pressing force is smaller than or equal to 20 tons, more preferred draining performance can be obtained without deformation of the draining roll 33. Accordingly, the pressing force is preferably set to smaller than or equal to 20 tons.

[0063] A mechanism that applies the pressing force through the draining roll 33 may be any of a spring or the like or a mechanism that can apply a constant pressing force such as a pneumatic mechanism or a hydraulic mechanism. For the purpose of adjusting bending of the draining roll 33, a mechanism that can maintain a constant pressing force is preferable. Furthermore, a mechanism that has a responsibility with which the pressing force can be varied in the longitudinal direction of the steel plate S is preferable.

[0064] As illustrated in Fig. 6, a draining purge nozzle 34 may be disposed instead of the draining roll 33 so as to inject a draining purge 35, thereby to remove the cooling water 7 remaining on the steel plate S. The draining purge 35 may be a liquid or a gas, or a combination of these may be injected. The gas is preferably used to maintain a temperature deviation of the steel plate S at a small value. Furthermore, from the viewpoint of production cost, air is more preferably used.

[0065] As illustrated in Fig. 7, both the draining roll 33 and the draining purge nozzle 34 may be used. Furthermore, either or both of the draining roll 33 and the draining purge nozzle 34 may be disposed on the entry side of the water-cooling device 3 to remove the cooling water 7 leaking from the water-cooling device 3. The reason for this is that the cooling start temperature of the steel plate S can be more precisely controlled.

[0066] Furthermore, either or both of the draining roll 33 and the draining purge nozzle 34 may be disposed not only on the entry side and the exit side of the water-cooling device 3, but also on the entry side and the exit side of the cooling zones so as to separate the individual cooling zones from each other. The reason for this is that, when the different amounts of water are injected from the different cooling zones, the zones of different amounts of cooling water are separated from each other, and thereby a temperature history of the steel plate S can be ensured. In addition, this allows free setting of the number of pairs of nozzles to be used by, for example, stopping the injection on the most entry side of the water-cooling device 3 to reduce the cooling time. Thus, the degree of variation of the temperature histories that can be kept for the steel plate to be cooled is increased, and thereby adequate cooling can be performed in accordance with required characteristics.

[0067] As illustrated in Fig. 8, large flow-rate cooling-water injection nozzles 36 (upper large flow-rate cooling-water injection nozzles 36a and lower large flow-rate cooling-water injection nozzles 36b) that can inject the amount of water out of a range of the invention may be installed on either or both of the entry side and the exit side of the water-cooling device 3 so as to be used in accordance with the target characteristics of the steel plate S for cooling the steel plate S. The number of cooling zones where the large flow-rate cooling-water injection nozzles 36 are installed is three on the entry side and three on the exit side of the water-cooling device 3 in Fig. 8. However, even when the number of cooling zones is other than three, the effect is not impaired.

[0068] Furthermore, as illustrated in Fig. 9, the cooling water injection nozzles 32 and the large flow-rate cooling-water injection nozzles 36 that can inject the amount of water out of the range of the invention may be disposed in the same cooling zones in the water-cooling device 3. The reason for this is that, when the mild cooling according to the present invention and the rapid cooling out of the range of the invention are combined with each other, more various temperature histories can be kept. Referring to Fig. 9, although the number of cooling zones where the cooling water injection nozzles 32 and the large flow-rate cooling-water injection nozzles 36 are disposed in the same cooling zones is seven in total, the effect is not impaired when the number of zones is other than seven. In addition to that, the large flow-rate cooling-water injection nozzles 36 that can inject the amount of water out of the range of the invention may be installed on either or both of the entry side and the exit side in the water-cooling device 3. Examples

[0069] Hereinafter, examples in which a steel plate was manufactured with the method for manufacturing the steel plate according to the present embodiment is described.

[0070] In a facility illustrated in Fig. 10, steel plates (having a thickness of 19 mm, 25 mm, 40 mm, a width of 3500 mm and a length of 7 m) in a room temperature state from which the scale had been removed in advance through shot blast processing were heated with the heating furnace to 840 °C in a nitrogen atmosphere. After that, the steel plates were cooled with a water-cooling device at a position separated from the heating furnace by 2.0 m to manufacture low

yield ratio heat-treated steel exhibiting a yield ratio of smaller than or equal to 80%.

[0071] The material of the steel plates being a cooling target was heated to 840 °C in heat cycle testing for a small sample performed in a laboratory, cooled to 450 °C at a cooling rate of 6 °C/s, and then subjected to testing in which the cooling target was subjected to rapid cooling to the room temperature. As a result, the microstructure became ferrite + bainite, and the yield ratio became 75%. Although the target microstructure of the steel plates S is ferrite + bainite, it has been confirmed, from other testing, that the characteristics are not significantly degraded even when part of the steel plates S in the thickness direction (for example, near the surface layer) becomes ferrite + martensite. Accordingly, when a steel plate is manufactured in an actual heat treatment facility with the same heat history as this heat history, a multiphase microstructure of ferrite + bainite is obtained, and the yield ratio is predicted as 75%. Thus, these are set as the target microstructure and the target low yield ratio. A yield ratio of smaller than or equal to 80% is regarded as satisfactory.

[0072] The water-cooling device 3 was disposed on the exit side of the heating furnace 2, and seven pairs of the upper and lower cooling water injection nozzles 32 were disposed in the water-cooling device 3. Furthermore, the thermometer 4 was disposed on the exit side of the water-cooling device 3, thereby to allow measurement of the surface layer temperature of the steel plates S having been cooled. The thermometer 4 is a scanning thermometer that measures a temperature distribution in the width direction of the steel plates S. Out of surface temperatures of the steel plates measured throughout the surfaces of the steel plates, a value obtained by subtracting the minimum value from the maximum value was evaluated as a temperature deviation in the steel plates.

[0073] In order to obtain the steel plate that is uniform throughout the surface, the steel plate is required to be cooled so that the cooling rate and the cooling stop temperature are uniform throughout the surface. Thus, the uniformity of the in-plane characteristics of the steel plates is evaluated with the cooling stop temperature and regarded as satisfactory when the temperature deviation in the steel plates falls within ± 25 °C.

[0074] As the cooling water injection nozzles 32, two types of nozzles including full-cone nozzles and flat spray nozzles were used. The speed of the cooling water injected from these nozzles was measured in advance in the laboratory. And the result of the measurement and the result of the operation condition were cross-checked to verify whether the measurements fall within the range of the present invention.

[0075] In the manufacture of the steel plates S, the number of cooling water injection nozzles 32 to be used, the water flow density of each zone, and the line speed of the steel plates were set so that an average cooling rate in a range from 800 °C to 650 °C in the surface layers of the steel plates is 4 °C/s and the surface layer temperature of the steel plates at the location of the thermometer 4 is 450 °C. The steel plates S discharged from the water-cooling device 3 were provided to rapid cooling being the downstream step and subjected to the rapid cooling to the room temperature with a known technique.

[0076] First, in order to grasp the relationship between the water flow density and the cooling rate, a preliminary experiment in which the steel plates S were heated to 1000 °C at high temperature and then water-cooled to 650 °C was performed. The steel plates S were heated to 1000 °C with the heating furnace 2 of the nitrogen atmosphere and then cooled with the water-cooling device 3. The number of cooling water injection nozzles 32 to be used, the water flow density of each zone, and the line speed of the steel plates were set so that the surface layer temperature of the steel plates S at the thermometer 4 on the exit side of the water-cooling device 3 is $650 \text{ }^{\circ}\text{C} \pm 25 \text{ }^{\circ}\text{C}$ and the average cooling rate in the range from 800 °C to 650 °C in the surface layers of the steel plates S is 4 to 10 °C/s.

[0077] As the cooling water injection nozzles 32, two types of nozzles including full-cone nozzles and flat spray nozzles were used, and the results with the respective nozzles were compared. Furthermore, a one-dimensional heat transfer simulation was performed based on the surface layer temperature of the steel plates S measured with the thermometer 4 on the exit side of the water-cooling device 3 and the heating temperature of the steel plates S, thereby to calculate the average cooling rate in the range from 800 °C to 650 °C in the surface layers of the steel plates S.

[0078] The relationship between the water flow density and the cooling rate in the cooling zones in the water-cooling device 3 is as illustrated in Fig. 11, and the relationship between the water flow density and the injection speed is as illustrated in Fig. 12. That is, the relationship between the water flow density and the cooling rate is not changed depending on the types of sprays. In contrast, the relationship between the water flow density and the injection speed is different. Even when injection was performed with the same water flow density, the injection speed of the cooling water was lower with the full-cone nozzles than with the flat spray nozzles.

[0079] Next, low yield ratio heat-treated steel exhibiting a yield ratio of smaller than or equal to 80% was manufactured. The steel plates S were heated to 840 °C with the heating furnace 2 with the nitrogen atmosphere and then cooled with the water-cooling device 3. The number of cooling water injection nozzles 32 to be used, the water flow density of each zone, and the line speed of the steel plates were set so that the surface layer temperature of the steel plates S at the thermometer 4 on the exit side of the water-cooling device 3 is $450 \text{ }^{\circ}\text{C} \pm 25 \text{ }^{\circ}\text{C}$ and the average cooling rate in the range from 800 °C to 650 °C in the surface layers of the steel plates S is 6 °C/s. The number of cooling water injection nozzles 32 to be used, the water flow density of each zone, and the line speed of the steel plates were set by using the results of the above-described cooling rate measurement experiment. As the cooling water injection nozzles 32, two types of

nozzles including full-cone nozzles and flat spray nozzles were used, and the results with the respective nozzles were compared.

[0080] Furthermore, a one-dimensional heat transfer simulation was performed based on the surface layer temperature of the steel plates S measured with the thermometer 4 on the exit side of the water-cooling device 3 and the heating temperature of the steel plates S, thereby to calculate the average cooling rate in the range from 800 °C to 650 °C in the surface layers of the steel plates S. The steel plates S discharged from the water-cooling device 3 were provided to rapid cooling being the downstream step and subjected to the rapid cooling to the room temperature with a known technique. After that, small samples were extracted from the manufactured steel plates S, a tensile test was performed on the small samples to measure the yield ratio, and microstructures were observed.

[Table 1]

	Thickness (mm)	Heating temperature (°C)	Cooling rate (°C/s)	Injection speed (m/s)	Cooling stop temperature (°C)	Temperature deviation (°C)	Yield ratio (%)	Microstructure	Scale removal
Example 1	16	840	4.1	2.6	440	±14	73	F+B	Yes
Example 2	25	840	3.9	2.6	459	±12	76	F+B	Yes
Example 3	40	840	4.0	2.6	450	±11	74	F+B	Yes
Example 4	16	840	4.0	2.6	451	±23	74	F+B	No
Comparative example 1	16	840	54.2	37.0	R.T.		86	F+M	Yes
Comparative example 2	25	840	42.3	37.0	R.T.		87	F+M	Yes
Comparative example 3	40	840	31.4	37.0	R.T.		82	F+M	Yes
Comparative example 4	16	840	0.3	0.2	470	±50	78	F+B	Yes

[0081] Manufacturing conditions of the steel plates S and results of characteristic evaluation testing are listed in Table 1. In the "Microstructure" column in Table 1, F means ferrite, B means bainite, and M means martensite, and in the "Cooling stop temperature" column, "R.T." means the room temperature.

[0082] Examples 1 to 3 were performed under conditions in which water-cooling was performed by reducing the injection speed of the cooling water with the full-cone spray nozzles. The steel plates S were able to be cooled at an intended cooling rate and an intended cooling stop temperature. The yield ratio fell within a satisfactory range. The conceivable reason for this is that, since the injection speed of the cooling water reduced, the transition temperature reduced and the film boiling state was able to be maintained until a low temperature is reached, and the average cooling rate in the range from 800 °C to 650 °C was able to be maintained until a lower temperature is reached.

[0083] Example 4 was performed under conditions in which the scale of the surface layer of the steel plate S was not removed by shot blasting. Although the steel plate S was able to be cooled at a substantially intended cooling rate and a substantially intended cooling stop temperature, compared to example 1 in which the scale was removed, the temperature deviation in the steel plate width direction increased. The conceivable reason for this is that an increase in the boiling transition temperature in part where the scale was generated caused changing to the nucleate boiling state partly, and accordingly, the cooling rate increased.

[0084] Comparative examples 1 to 3 were performed under conditions in which water-cooling was performed by accelerating the injection speed of the cooling water, with the flat spray nozzles, to values out of the range of the invention. Although the cooling conditions were set by using the results of the above-described cooling rate measurement experiment, the cooling stop temperature reduced to the room temperature. Accordingly, a correct cooling rate was unclear. Thus, testing for identifying the cooling rate was separately performed with the number of zones reduced. As a result, the cooling rate increased to values out of the range of the present invention. Also, since the cooling rate was high, the yield ratio fell outside the satisfactory range. The conceivable reason for this is that, since the boiling transition temperature increased and the cooling assumed the nucleate boiling state, the average cooling rate in the range from 800 °C to 650 °C was not able to be maintained until a lower temperature is reached.

[0085] Comparative example 4 was performed under conditions in which water-cooling was performed by decelerating the injection speed of the cooling water, with the flat spray nozzles, to values out of the range of the invention. The cooling rate is substantially equivalent to that of natural cooling. Furthermore, the temperature deviation in the width direction of the steel plate is unsatisfactory. The conceivable reason for this is that, since an injection flow velocity of the sprays reduced and the cooling water was not able to be stably injected, the water concentrated only immediately below the sprays.

Reference Signs List

[0086]

- 1 heat treatment facility (steel plate manufacturing facility)
- 2 heating furnace
- 3 water-cooling device
- 4 thermometer
- 5 cooling zone
- 6 table roll
- 7 cooling water
- 9 descaling device
- 10 control device
- 11 higher-level computer
- 12 water-cooling condition computation section
- 13 water-cooling operation condition output section
- 32 cooling water injection nozzle
- 32a upper cooling water injection nozzle
- 32b lower cooling water injection nozzle
- 33 draining roll
- 34 draining purge nozzle
- 35 draining purge
- 36 large flow-rate cooling-water injection nozzle
- 36a upper large flow-rate cooling-water injection nozzle
- 36b lower large flow-rate cooling-water injection nozzle
- S steel plate

Claims

1. A method for manufacturing a steel plate in which water-cooling is performed on the steel plate, wherein
 - 5 a water-cooling device that includes a plurality of combinations of at least one pair of upper and lower cooling water injection nozzles arranged in a traveling direction of the steel plate is used, and wherein an injection speed of cooling water of the cooling water injection nozzles is higher than or equal to 0.4 m/s and lower than or equal to 30 m/s to perform the water-cooling on the steel plate.
- 10 2. The method for manufacturing a steel plate according to Claim 1, wherein a surface layer cooling rate of the steel plate in the water-cooling device is higher than or equal to 0.4 °C/s and lower than or equal to 29 °C/s.
- 15 3. The method for manufacturing a steel plate according to Claim 1 or 2, wherein descaling is performed on the steel plate before the water-cooling.
4. The method for manufacturing a steel plate according to any one of Claims 1 to 3, wherein an oxide scale removing process and heating are performed on the steel plate before the water-cooling.
- 20 5. The method for manufacturing a steel plate according to any one of Claims 1 to 4, wherein a temperature of either or both of upper and lower surfaces of the steel plate is measured after the water-cooling.
- 25 6. The method for manufacturing a steel plate according to any one of Claims 2 to 5, wherein the surface layer cooling rate is controlled by controlling an amount of the cooling water injected from the cooling water injection nozzles.
- 30 7. The method for manufacturing a steel plate according to any one of Claims 1 to 6, wherein a cooling stop temperature of the steel plate is controlled by controlling a number of the cooling water injection nozzles and a line speed of the steel plate, and the cooling stop temperature represented by a surface layer temperature of the steel plate is greater than or equal to 350 °C.
8. A steel plate manufacturing facility that performs water-cooling on the steel plate, the facility comprising:
 - 35 a water-cooling device that includes a plurality of combinations of at least one pair of upper and lower cooling water injection nozzles arranged in a traveling direction of the steel plate; and
 - a control device that controls an injection speed of cooling water injected from the cooling water injection nozzles to be higher than or equal to 0.4 m/s and lower than or equal to 30 m/s.
- 40 9. The steel plate manufacturing facility according to Claim 8, wherein the control device controls a surface layer cooling rate of the steel plate in the water-cooling device to be higher than or equal to 0.4 °C/s and lower than or equal to 29 °C/s.
- 45 10. The steel plate manufacturing facility according to Claim 8 or 9, the facility further comprising: a descaling device disposed on an entry side of the water-cooling device.
- 50 11. The steel plate manufacturing facility according to any one of Claims 8 to 10, the facility further comprising: a thermometer that is disposed on an exit side of the water-cooling device and measures a temperature of either or both of upper and lower surfaces of the steel plate.
- 55 12. The steel plate manufacturing facility according to any one of Claims 8 to 11, wherein the control device further controls an amount of the cooling water injected from the cooling water injection nozzles.
13. The steel plate manufacturing facility according to any one of Claims 8 to 12, wherein the control device controls a number of cooling water injection nozzles and a line speed of the steel plate.

FIG. 1

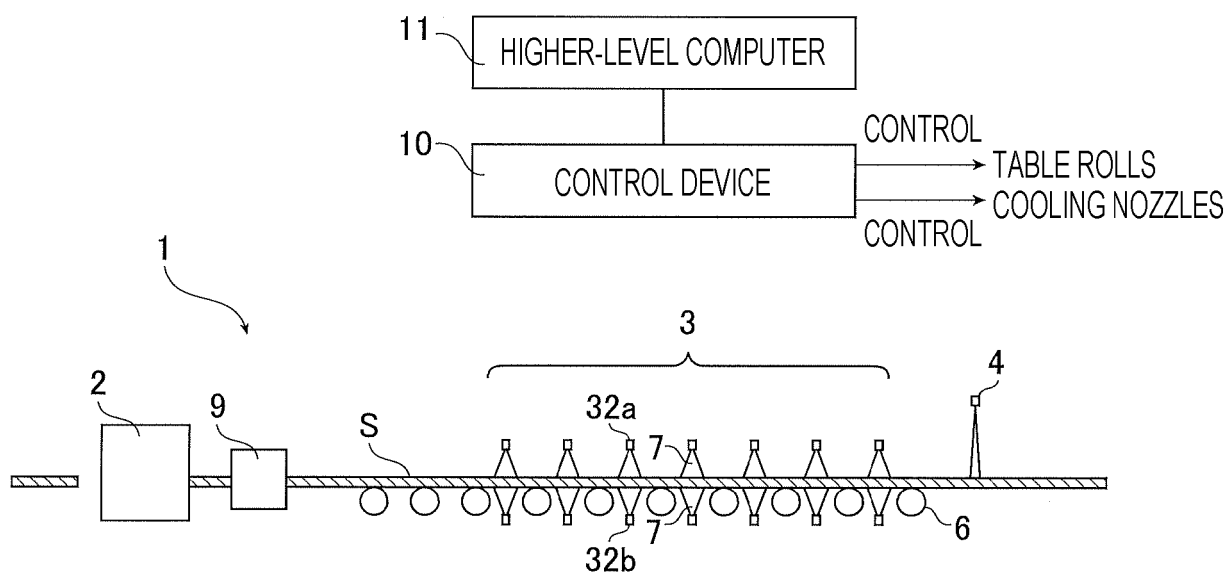


FIG. 2

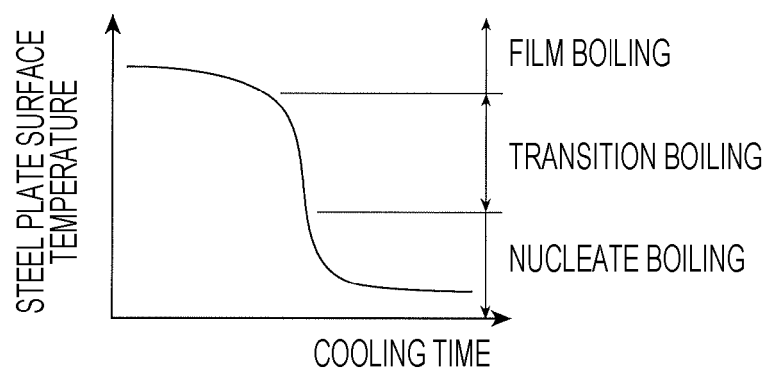


FIG. 3

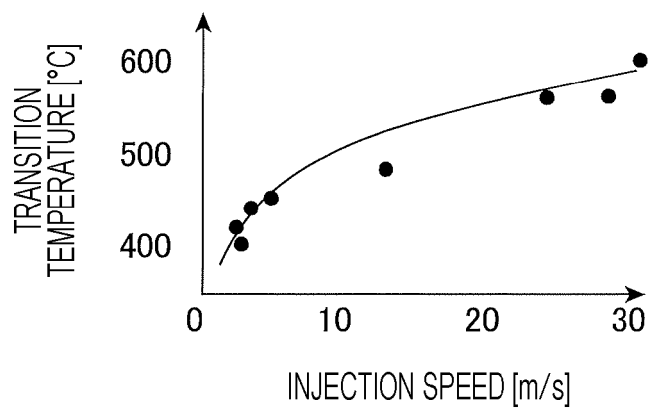


FIG. 4

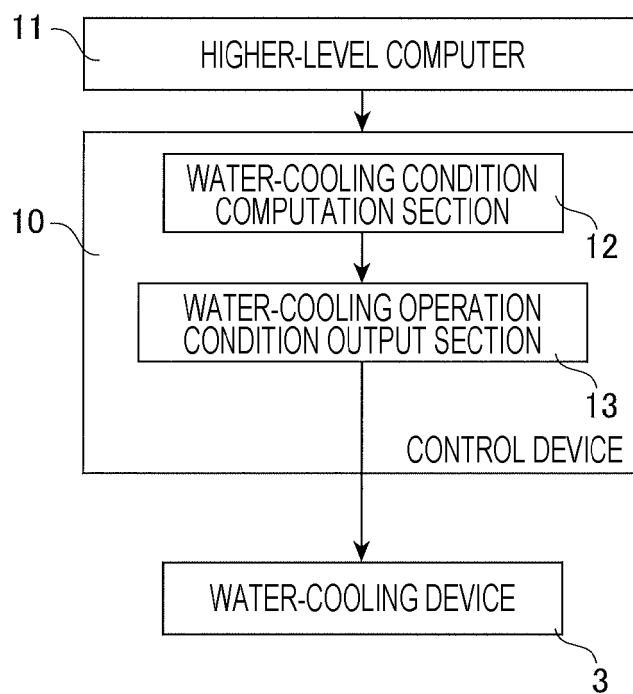


FIG. 5

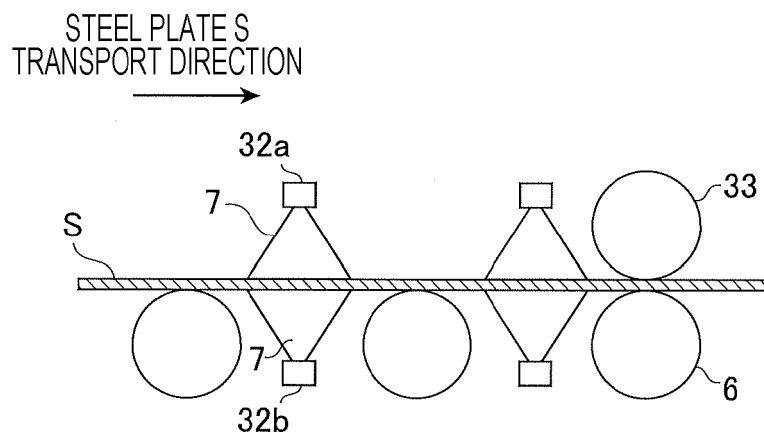


FIG. 6

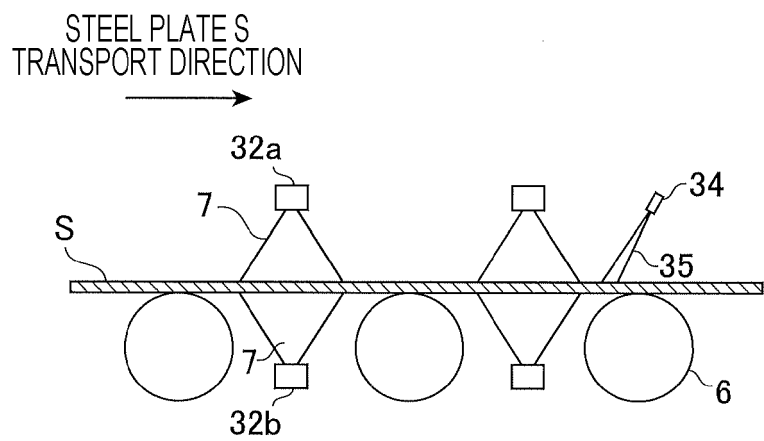


FIG. 7

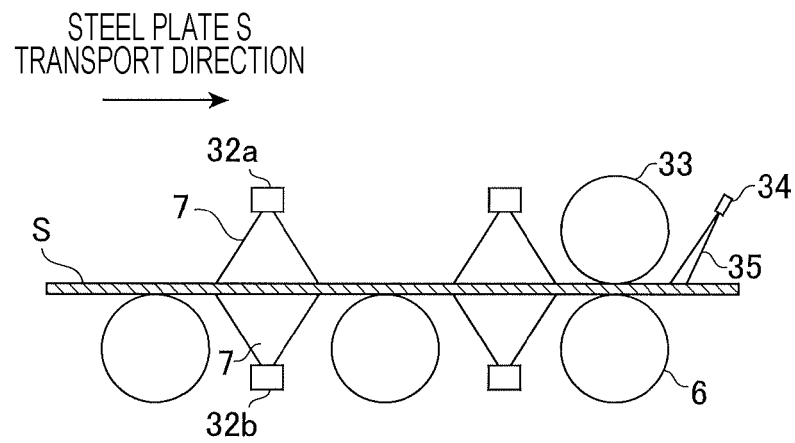


FIG. 8

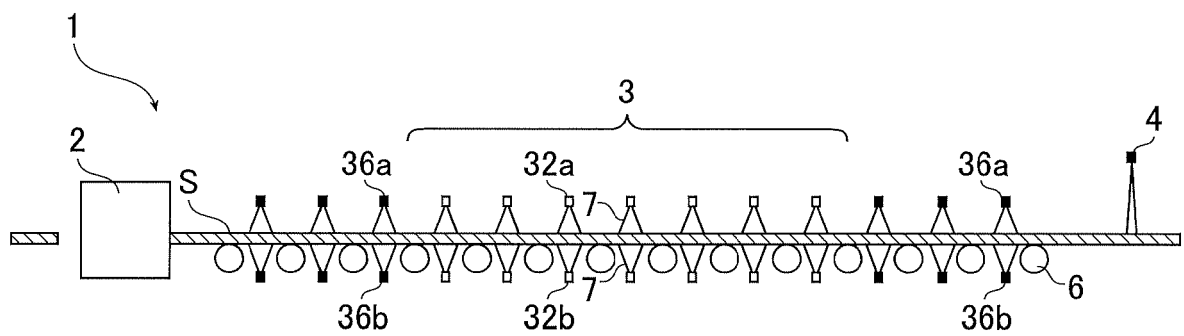


FIG. 9

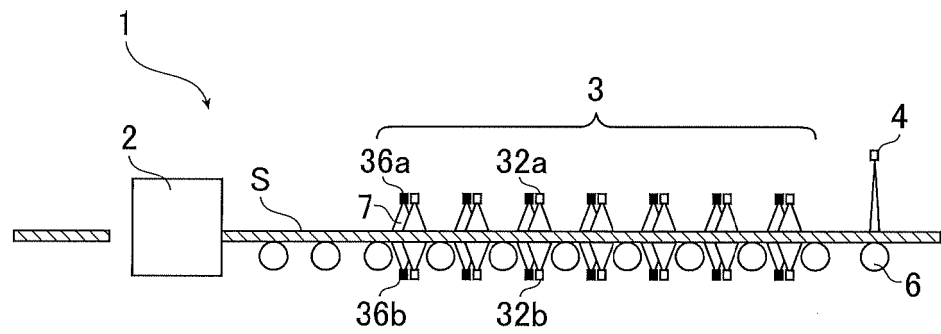


FIG. 10

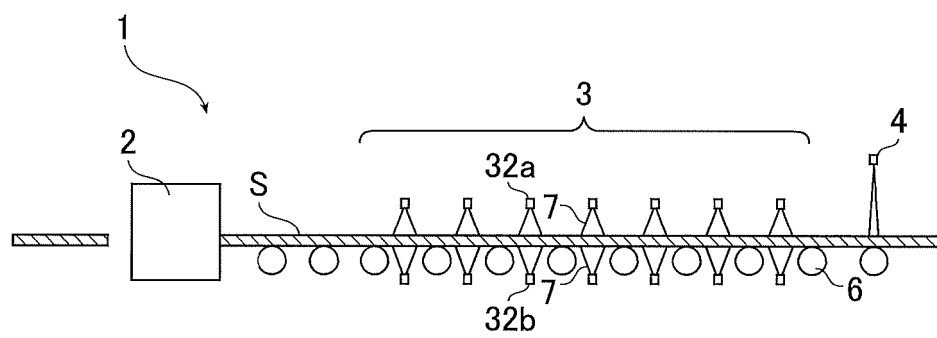


FIG. 11

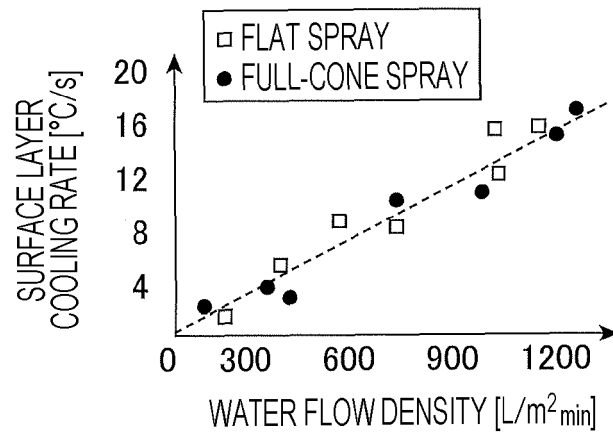
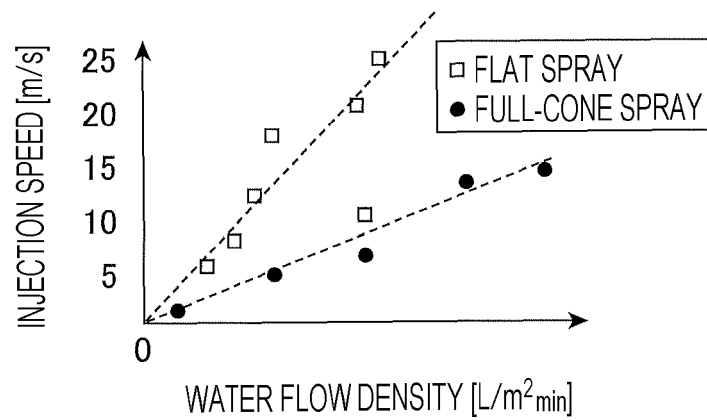


FIG. 12



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2022/028414

A. CLASSIFICATION OF SUBJECT MATTER B21B 45/02(2006.01)i; B21B 45/06(2006.01)i; B21C 51/00(2006.01)i; C21D 1/00(2006.01)i; B21B 38/00(2006.01)i FI: C21D1/00 123A; B21B38/00 C; B21B45/02 320T; B21B45/06; B21C51/00 E 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) C21D1/00; B21B38/00; B21B45/02; B21B45/06; B21C51/00 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 <table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>X</td> <td>JP 2019-505388 A (ARCELORMITTAL) 28 February 2019 (2019-02-28) claims, paragraphs [0018]-[0042], [0140]-[0156], [0166]-[0171], table 3</td> <td>1-2, 8-9, 13</td> </tr> <tr> <td>Y</td> <td></td> <td>3-6, 10-12</td> </tr> <tr> <td>A</td> <td></td> <td>7</td> </tr> <tr> <td>X</td> <td>WO 2010/114083 A1 (JFE STEEL CORPORATION) 07 October 2010 (2010-10-07) claims, paragraphs [0089]-[0102]</td> <td>1, 5, 7-8, 11, 13</td> </tr> <tr> <td>Y</td> <td></td> <td>2-4, 6, 9-10, 12</td> </tr> <tr> <td>X</td> <td>WO 2010/110473 A1 (JFE STEEL CORPORATION) 30 September 2010 (2010-09-30) claims, paragraphs [0014]-[0017], [0051]-[0059]</td> <td>1, 3-4, 7-8, 10, 13</td> </tr> <tr> <td>Y</td> <td></td> <td>2-6, 9, 10-12</td> </tr> <tr> <td>Y</td> <td>WO 2019/087805 A1 (JFE STEEL CORPORATION) 09 May 2019 (2019-05-09) paragraph [0035]</td> <td>2-6, 9-12</td> </tr> <tr> <td>A</td> <td>JP 2016-163898 A (KOBELITE LTD) 08 September 2016 (2016-09-08)</td> <td>1-13</td> </tr> </tbody> </table>	Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	X	JP 2019-505388 A (ARCELORMITTAL) 28 February 2019 (2019-02-28) claims, paragraphs [0018]-[0042], [0140]-[0156], [0166]-[0171], table 3	1-2, 8-9, 13	Y		3-6, 10-12	A		7	X	WO 2010/114083 A1 (JFE STEEL CORPORATION) 07 October 2010 (2010-10-07) claims, paragraphs [0089]-[0102]	1, 5, 7-8, 11, 13	Y		2-4, 6, 9-10, 12	X	WO 2010/110473 A1 (JFE STEEL CORPORATION) 30 September 2010 (2010-09-30) claims, paragraphs [0014]-[0017], [0051]-[0059]	1, 3-4, 7-8, 10, 13	Y		2-6, 9, 10-12	Y	WO 2019/087805 A1 (JFE STEEL CORPORATION) 09 May 2019 (2019-05-09) paragraph [0035]	2-6, 9-12	A	JP 2016-163898 A (KOBELITE LTD) 08 September 2016 (2016-09-08)	1-13
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

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