



(11)

**EP 4 282 991 A1**

(12)

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

(43) Date of publication:

**29.11.2023 Bulletin 2023/48**

(21) Application number: **22779522.6**

(22) Date of filing: **04.02.2022**

(51) International Patent Classification (IPC):

**C21D 8/00** (2006.01)

**C21D 9/04** (2006.01)

**C22C 38/00** (2006.01)

**C22C 38/60** (2006.01)

(52) Cooperative Patent Classification (CPC):

**C21D 9/04; C21D 8/00; C22C 38/00; C22C 38/60**

(86) International application number:

**PCT/JP2022/004530**

(87) International publication number:

**WO 2022/209293 (06.10.2022 Gazette 2022/40)**

(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**

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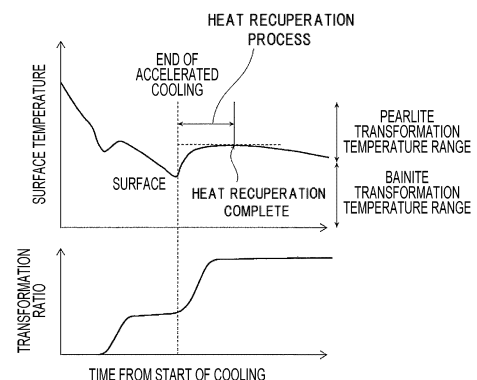
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(54) **RAIL AND METHOD FOR MANUFACTURING SAME**

(57) An object is to provide a method for manufacturing a high-hardness and high-quality rail through a simple cooling process even in the presence of temperature variations in the longitudinal direction of the rail before the start of cooling.

A rail manufacturing method includes a step of accelerated cooling a rail having a temperature equal to or higher than an austenite region temperature. In the rail manufacturing method, austenite represents a portion of a region from a cooled surface of a rail head to a depth of 5 mm at the end of accelerated cooling, and the temperature of a rail head surface at the completion of heat recuperation after the end of accelerated cooling is in a pearlite transformation temperature range.

FIG. 1



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## Description

## Technical Field

5 **[0001]** The present invention relates to a rail that exhibits enhanced wear resistance of the rail head as a result of accelerated cooling of a hot rail that has been hot-rolled at or above an austenite region temperature or has been heated to or above an austenite region temperature with a cooling medium (such as air, water, or mist). The present invention also relates to a method for manufacturing the rail.

## 10 Background Art

**[0002]** A general method will be described for the manufacturing of conventional high-hardness rails in which fine pearlite microstructures are formed in the rail head to enhance the wear resistance of the rail head.

15 **[0003]** A rail that has been hot-rolled at or above an austenite region temperature or has been heated to or above an austenite region temperature is delivered into a heat treatment device while being in an upright state (the top of the head is on the upside and the bottom of the foot is on the downside). In this case, the rail that is delivered into the heat treatment device is as-rolled with a length of, for example, about 100 m, or is sometimes divided (hereinafter, sawed) into smaller rails each having a length of, for example, about 25 m. When the basic process is such that a rail is sawed and then cooled, the heat treatment device is sometimes divided into zones with the corresponding length.

20 **[0004]** In the heat treatment device, the foot of the rail is restrained with, for example, clamps, and the head top surface, the head side surface, the foot bottom surface, and, if necessary, the web surface are forcibly cooled with a cooling medium (such as air, water, or mist). Fine pearlite microstructures are formed in the whole of the head including the inside of the head by controlling the temperature history.

25 **[0005]** After the heat treatment is completed, the rail is delivered in an upright or overturned state to a cooling bed and is allowed to be naturally cooled nearly to room temperature. The rail is then processed into a final product through such steps as leveling and inspection.

30 **[0006]** Causing pearlite transformation to occur at a low temperature is effective for increasing the hardness by accelerated cooling. The transformation temperature can be lowered by increasing the cooling rate. Because the inside of the head is cooled by the conduction of heat from the head surface, a relatively long time of cooling is necessary to ensure that the rail is increased in hardness to the inside of the head.

**[0007]** When, however, the cooling rate is high and an excessively large amount of heat is cooled, microstructures other than pearlite, for example, bainite microstructures and martensite microstructure, are disadvantageously formed near the surface being cooled. In contrast to pearlite microstructures, bainite microstructures cause a greater decrease in wear resistance with increasing fraction thereof, and martensite microstructures significantly lower toughness.

35 **[0008]** Thus, a precise control of temperature history is required in order to ensure that fine pearlite microstructures will be formed by accelerated cooling. Patent Literature 1 describes a method of controlling the temperature history while monitoring transformation behaviors with a thermometer installed in a cooling device.

## Citation List

40

## Patent Literature

**[0009]** PTL 1: WO 2014/157198

## 45 Summary of Invention

## Technical Problem

50 **[0010]** Fig. 2 schematically illustrates a pressure schedule of a top air header for performing desired cooling in Patent Literature 1, and a history of rail head surface temperature. As illustrated in Fig. 2, cooling is started from a cooling start temperature in the austenite region, and the temperature starts to rise due to transformation heating at a timing indicated by  $t_1$  in the figure. If the temperature rise is too large, the transformation occurs at a high temperature and results in low hardness. In order to prevent this, the cooling capacity needs to be increased by increasing the header pressure almost at the same time as or slightly before the temperature starts to rise. In this manner, the temperature rise due to transformation heating can be suppressed and the hardness can be increased. In this process, transformation occurs later in the inside than at the surface. In order to increase the hardness of the inside, it is necessary to cool the surface to a temperature in the bainite formation region and thereby to increase the cooling rate in the inside by heat conduction. However, the completion of the transformation in the inside cannot be grasped by the measurement of temperatures

being cooled from the rail surface. Thus, accelerated cooling is effected to cool a large amount of heat, and the temperature of the head surface that is recuperated after the end of the accelerated cooling is generally below the pearlite transformation temperatures.

**[0011]** However, a rail may have temperature variations in the longitudinal direction before the start of cooling. When such a rail is cooled over the entire length in a controlled manner by the method described in Patent Literature 1, the transformation starts at varied timings depending on the temperature variations. This requires that thermometers be installed at all the locations where a variation is present, thus increasing equipment installation costs. Moreover, even if thermometers are installed, desired control may fail depending on conditions. In the case of, for example, air-blast cooling, cooling air is usually supplied from one blower to a plurality of cooling headers. When the cooling rate in this type of cooling needs to be changed widely in order to deal with temperature variations in the longitudinal direction, the flow rate and pressure control valves installed on the individual headers cannot manage such needs and fail to control the cooling in accordance with transformation behaviors. As a result, pearlite transformation occurs at a high temperature to result in low hardness, or pearlite transformation does not complete during accelerated cooling and large amounts of bainite microstructures and martensite microstructures are formed.

**[0012]** Heating, such as IH, is a possible approach to correcting temperature variations in the longitudinal direction of a rail before the start of cooling, but adds an extra equipment installation cost. Instead of simultaneous cooling over the entire length, a rail may be cooled by being passed from one end to the other end through the inside of a cooling device. In this case, however, the cooling device is extended in length if the cooling time is long. As a result, extra equipment installation costs are added, such as the need of thermal rundown compensation by IH.

**[0013]** Furthermore, temperature variations are, for example, variations from material to material or variations within a cross section of a head. Variations in temperature and time during heating, rolling, and travel to an accelerated cooling device produce temperature variations from material to material. Because a rail that has been rolled is delivered to an accelerated cooling device in an overturned state, heat dissipation conditions differ from place to place of the rail head. This generates temperature differences in a cross section of the head.

**[0014]** Therefore, the present invention has been made to solve the problems discussed above. It is therefore an object of the present invention to provide a method for manufacturing a high-hardness and high-quality rail through a simple cooling process even in the presence of temperature variations in the rail before the start of cooling. Here, "high-hardness" means a surface hardness of HB430 or above and an internal hardness of HB385 or above. Furthermore, "high-quality" means that the formation ratio of bainite, which lowers wear resistance, is 15% or less at a position from the cooled surface of the rail head to a depth of 5 mm. Solution to Problem

**[0015]** As a result of extensive studies, the authors have discovered that when bainite microstructures are formed, a large proportion thereof occurs during natural cooling after the end of accelerated cooling. That is, the authors have found that austenite untransformed during accelerated cooling is transformed into pearlite or bainite depending on the temperature history during the process of heat recuperation and subsequent natural cooling after the end of accelerated cooling.

**[0016]** At the end of accelerated cooling, as illustrated in Fig. 3, heat is recuperated by heat conduction so as to substantially equalize the sectional temperature distribution that has occurred during the accelerated cooling, with the result that the surface temperature increases. If the pearlite transformation is incomplete and austenite remains at the end of accelerated cooling, and further if the temperature is in the bainite transformation temperature range during the heat recuperation process, the residual austenite is transformed into bainite. The amount of bainite thus formed is significant if substantially no pearlite transformation has occurred during the accelerated cooling. Incidentally, in the graph of transformation ratio in Fig. 3, 100 - transformation ratio (%) is the ratio of residual austenite.

**[0017]** On the other hand, as illustrated in Fig. 1, even if the pearlite transformation is incomplete and austenite remains at the end of accelerated cooling, and further even if the temperature is in the bainite formation temperature range, the temperature reaches again the pearlite transformation temperature range during the heat recuperation process. Most of the residual austenite is thus transformed into pearlite during the heat recuperation process and the subsequent natural cooling. The authors have found that the desired pearlite microstructures are thus obtained.

**[0018]** The present invention has been made based on the above findings. A summary of the present invention resides in the following.

[1] A rail manufacturing method including a step of accelerated cooling a rail having a temperature equal to or higher than an austenite region temperature, wherein austenite represents 70% or less of a region from a cooled surface of a rail head to a depth of 5 mm at the end of accelerated cooling, and the temperature of a rail head surface at the completion of heat recuperation after the end of accelerated cooling is in a pearlite transformation temperature range.

[2] The rail manufacturing method described in [1], wherein the maximum temperature of the rail head surface in the heat recuperation process after the end of accelerated cooling is at or above the lower limit of the pearlite transformation temperature range and is at or below 75°C above the lower limit of the pearlite transformation tem-

perature range.

[3] The rail manufacturing method described in [1] or [2], which includes allowing the rail after the end of accelerated cooling to be naturally cooled, and, after the temperature of the rail head surface falls to 200°C or below, cooling the rail at a rate of 1°C/s or more.

[4] A rail having a bainite formation ratio of 15% or less in a region from a cooled surface of a rail head to a depth of 5 mm.

#### Advantageous Effects of Invention

**[0019]** The manufacturing method of the present invention can produce a high-hardness and high-quality rail even in the presence of temperature variations in the rail before the start of cooling.

#### Brief Description of Drawings

**[0020]**

[Fig. 1] Fig. 1 is a schematic view illustrating a relationship according to the present invention between a temperature history of a rail head surface from the start of accelerated cooling, and the transformation ratio in a region from the cooled surface of the rail head to a depth of 5 mm.

[Fig. 2] Fig. 2 is a schematic view of a pressure schedule of a top air header for cooling a rail head surface, and a history of the rail head surface temperature according to Patent Literature 1.

[Fig. 3] Fig. 3 is a schematic view illustrating a relationship according to COMPARATIVE EXAMPLE between a temperature history of a rail head surface and the transformation ratio in a region from the cooled surface to a depth of 5 mm when the temperature at the completion of heat recuperation after the end of accelerated cooling is in a bainite transformation temperature range.

#### Description of Embodiments

**[0021]** A manufacturing method of the present invention will be described below with reference to the drawings.

**[0022]** A case will be discussed in which, as illustrated in Fig. 1, pearlite transformation is incomplete in a region from a cooled surface of a rail head to a depth of 5 mm, and austenite remains at the end of accelerated cooling, and the temperature of the rail head surface is in the bainite formation temperature range. The temperature reaches again the pearlite transformation temperature range in the subsequent heat recuperation process, and consequently most of the residual austenite is transformed into pearlite during the heat recuperation process and the subsequent natural cooling. The ratio of the residual austenite is usually 70% or less. In this process, fine pearlite microstructures may be obtained by controlling accelerated cooling in such a manner that the temperature of the rail head surface at the completion of heat recuperation after the end of accelerated cooling is in the pearlite transformation temperature range. The amount of the residual austenite may be determined by a conventional method.

**[0023]** Here, a trace amount of bainite is sometimes generated in the bainite formation temperature range during accelerated cooling and the heat recuperation process. When the bainite formation ratio in a region from the cooled surface of the rail head to a depth of 5 mm is 15% or less, the difference in wear resistance from full pearlite, that is, 100% pearlite, is negligible. For example, the incompleteness of pearlite transformation and the presence of residual austenite after accelerated cooling may be confirmed by measurement using a transformation ratio meter, or with Thermecmaster that reproduces temperatures actually measured during cooling. Alternatively, for example, a method may be adopted in which the rail is compared with a rail obtained in such a manner that the cooling time is intentionally extended to bring the temperature range after heat recuperation to the bainite transformation temperature range. The term "bainite transformation temperature range" as used herein indicates a temperature range in which bainite is formed when the rail is held in an isothermal state. The bainite or pearlite transformation temperature range may be grasped beforehand by preparing an isothermal transformation curve using, for example, a test specimen.

**[0024]** The temperature of the rail head surface is a value obtained by measuring the temperature of a corner of the rail head with a radiation thermometer. When the rail is delivered in an upright position after the end of accelerated cooling, the temperature in a cross section of the rail head is substantially equalized during the heat recuperation process. Thus, the temperature may be measured at any position of a region including the surfaces of the head corners on both sides as well as the surface of the central portion of the head. The region from the cooled surface of the rail head to a depth of 5 mm indicates that a value is an average of values of microstructures present in a region from the surface of the central portion and the surfaces of the head corners on both sides of the rail head to a depth of 5 mm.

**[0025]** The maximum temperature of the rail head in the heat recuperation process after the end of accelerated cooling is preferably at or below 75°C above the lower limit of the pearlite transformation temperature range. In this case, finer pearlite is formed and the hardness of the rail is further increased. More preferably, the maximum temperature is at or

below 50°C above the lower limit of the pearlite transformation temperatures.

**[0026]** When the rail is cooled nearly to room temperature on a cooling bed, it is preferable that the rail be allowed to be naturally cooled until the temperature of the rail head surface falls to 200°C or below, and be thereafter cooled at a rate of 1°C/s or more. When the rail temperature has fallen to 200°C or below, the transformation in the rail has completed and characteristics are no longer affected. In this manner, the amount of natural cooling time can be reduced. Furthermore, such cooling on the cooling bed does not affect rail warpage. If natural cooling is continued even after the temperature has fallen to 200°C or below, the rail takes one hour or more to be cooled nearly to room temperature because the temperature difference from room temperature becomes smaller. The amount of treatment time on the cooling bed can be significantly reduced by cooling the rail at a cooling rate of 1°C/s or more.

**[0027]** The time in which the temperature falls to 200°C or below may be grasped beforehand, and the cooling on the cooling bed may be started after the lapse of predetermined time. Alternatively, the temperature of the rail head surface may be measured with a thermometer, and the cooling may be started after the temperature has been conformed to be 200°C or below. The cooling on the cooling bed may be performed in a known manner, such as cooling by water spray from above the rail.

**[0028]** It is not necessary to constantly measure the temperature of the rail head during the heat recuperation process and the subsequent natural cooling after the end of accelerated cooling. The temperature may be appropriately measured at a timing of 30 seconds or more and 150 seconds or less after the end of accelerated cooling. If the timing is earlier than 30 seconds, the heat recuperation is not complete yet, and determination is impossible as to whether the temperature of the rail head surface is within the desired pearlite transformation temperature range, causing a risk that the hardness of the rail may be lowered. If the timing is later than 150 seconds, the temperature falls to a great extent during natural cooling after the heat recuperation process. Consequently, it is difficult to grasp the temperature experienced during the heat recuperation process, and there is a risk that the hardness of the rail may be lowered. In general, a rail that has been accelerated cooled is transferred to a cooling bed and is allowed to be naturally cooled nearly to room temperature. Thus, it is preferable to measure the temperature during the travel to the cooling bed at a timing of 30 seconds or more and 150 seconds or less after the end of accelerated cooling. In this manner, the measurement over the total length of the rail is feasible with a single thermometer.

**[0029]** If the measured result is not the desired temperature, the amount of cooling may be appropriately controlled for the next and later rails. If the temperature is high, the amount of cooling may be appropriately increased, specifically, the cooling capacity may be increased by increasing the flow rate of a coolant that is injected, or the cooling time may be extended. If the temperature is low, the amount of cooling may be appropriately reduced, specifically, the cooling capacity may be lowered by lowering the flow rate of a coolant that is injected, or the cooling time may be shortened.

**[0030]** Regarding the cooling rate during accelerated cooling, it is preferable that the rail head surface be cooled at 1°C/s or more and 7°C/s or less to induce pearlite transformation in the vicinity of the surface, specifically, in a region from the cooled surface of the rail head surface to a depth of 5 mm. The cooling rate is more preferably 4°C/s or more and 6°C/s or less. When the cooling is performed by, for example, blast cooling, the cooling capacity decreases as the temperature is lowered. It is therefore preferable to increase the flow rate as the rail temperature is lowered.

**[0031]** When transformation starts near the surface, the temperature is raised by the heat generated by the transformation. The increase in temperature due to the heat of transformation is preferably 50°C or less, and more preferably 30°C or less.

**[0032]** After the increase in temperature due to the heat of transformation near the surface has stopped, the rail is preferably cooled at 1°C/s or more and 5°C/s or less, more preferably at 1.5°C/s or more and 2.5°C/s or less. Cooling at more than 5°C/s entails a larger cooling device and adds equipment costs. Furthermore, adjustments in the amount of cooling vary greatly, and more accurate control of the cooling device is required to increase the equipment costs.

**[0033]** In the rail head cooled by the above cooling method, the bainite formation ratio in a region from the cooled surface to a depth of 5 mm should be 15% or less. In the remaining microstructures, the pearlite formation ratio is preferably 85% or more. If the bainite formation ratio is more than 15%, wear resistance is inferior compared to full pearlite. Incidentally, the bainite formation ratio here is the area fraction of bainite visible by microstructure observation with a usual optical microscope. The formation ratio of microstructures other than bainite similarly means the area fraction.

**[0034]** The chemical composition of the rail may be one falling in the conventionally known range. For example, the chemical composition may have, by mass%, C content: 0.7 or more and 1.00% or less, Si content: 0.20 or more and 1.20% or less, Mn content: 0.20 or more and 1.50% or less, P content: 0.035% or less, S content: 0.012% or less, and Cr content: 0.20 or more and 1.50% or less, and may optionally include at least one selected from Cu, Ni, Mo, V, Nb, Al, Ti, and Sb each in an amount of 0.01 or more and 1.00% or less, and at least one of B, Ca, Mg, and REM each in an amount of 0.001 or more and 0.10% or less, the balance being preferably iron and inevitable impurities. The steel microstructures other than the region from the cooled surface of the rail head of the present invention to a depth of 5 mm are not particularly limited and may be conventional.

## EXAMPLES

**[0035]** A long rail that had a chemical composition described in Table 1 and had been hot-rolled at 900°C was inserted into a cooling device almost at the same time over the entire length. A header was brought closer to the rail, and air cooling was started from a surface temperature of the rail head of 770°C. During cooling, the temperature of a corner of the rail head was measured with a radiation thermometer to measure the cooling rate of the rail head surface. The rail was cooled at 5.5°C/s from the start of accelerated cooling until the onset of temperature rise due to the heat of transformation near the rail surface, and was cooled at 1.5°C/s after the increase in temperature due to the heat of transformation near the surface had stopped. After the end of accelerated cooling, the rail was removed from the cooling device and was delivered to a cooling bed. During this process, the temperature of the head surface of the rail being delivered to the cooling bed was measured as the temperature of the rail head surface at the completion of heat recuperation. The amount of cooling time after the increase in temperature due to the heat of transformation near the surface had stopped was adjusted so that the temperature measured above would be a predetermined value.

[Table 1]

| Chemical composition | C    | Si   | Mn   | P     | S     | Cr   | V    |
|----------------------|------|------|------|-------|-------|------|------|
| Mass%                | 0.83 | 0.79 | 0.64 | 0.011 | 0.004 | 0.85 | 0.02 |

The balance is Fe and inevitable impurities.

**[0036]** After the rail temperature became ambient, a sample was cut in accordance with JIS Z 2243. The sample was analyzed to measure the hardness at a position on the surface of the center of the head and at a position 23 mm below that surface, and to investigate the average pearlite formation ratio from the surface of the central portion of the head and the surfaces of the head corners on both sides to a depth of 5 mm. The results are described in Table 2. Furthermore, the history of surface temperatures that were measured was reproduced with Thermecmastor to investigate transformation behaviors during the cooling. All the microstructures other than pearlite were bainite. An isothermal transformation curve prepared based on the components described in Table 1 showed that the pearlite transformation temperature range was 750 to 525°C. HB430 or higher surface hardness was evaluated as good. HB385 or higher internal hardness was evaluated as good. The range of pearlite formation ratio at room temperature according to the present invention was 85% or more, and the microstructures were judged to be of higher quality with increasing pearlite formation ratio at room temperature. The difference of 100% minus the pearlite formation ratio at the end of accelerated cooling is regarded as the amount of residual austenite.

[Table 2]

|             | Rail head surface temperature at the completion of heat recuperation | Surface hardness | Internal hardness | Pearlite formation ratio at the end of accelerated cooling | Pearlite formation ratio at room temperature | Bainite formation ratio at room temperature |
|-------------|----------------------------------------------------------------------|------------------|-------------------|------------------------------------------------------------|----------------------------------------------|---------------------------------------------|
| EX. 1       | 610°C                                                                | HB438            | HB391             | 35%                                                        | 95%                                          | 5%                                          |
| EX. 2       | 550°C                                                                | HB451            | HB402             | 35%                                                        | 90%                                          | 10%                                         |
| COMP. EX. 1 | 450°C                                                                | HB414            | HB403             | 35%                                                        | 35%                                          | 65%                                         |

**[0037]** In EXAMPLE 1, the hardnesses and the microstructures were good because of the temperature of the rail head surface at the completion of heat recuperation being 610°C. EXAMPLE 2 attained higher hardnesses than EXAMPLE 1 as a result of the temperature of the rail head surface at the completion of heat recuperation being 550°C. In both EXAMPLES, the pearlite transformation ratio at the rail surface immediately after the end of accelerated cooling was 35%, but pearlite transformation occurred during the subsequent heat recuperation process.

**[0038]** In contrast, in COMPARATIVE EXAMPLE, the pearlite transformation ratio at the rail surface immediately after the end of accelerated cooling was 35%, but pearlite transformation did not occur during the heat recuperation process after the end of accelerated cooling because the temperature of the rail head surface at the completion of heat recuperation was 450°C. As a result, a large amount of bainite was formed in the vicinity of the surface to cause a significant decrease in surface hardness.

Claims

1. A rail manufacturing method comprising a step of accelerated cooling a rail having a temperature equal to or higher than an austenite region temperature, wherein

austenite represents 70% or less of a region from a cooled surface of a rail head to a depth of 5 mm at the end of accelerated cooling, and  
the temperature of a rail head surface at the completion of heat recuperation after the end of accelerated cooling is in a pearlite transformation temperature range.

2. The rail manufacturing method according to claim 1, wherein the maximum temperature of the rail head surface in the heat recuperation process after the end of accelerated cooling is at or above the lower limit of the pearlite transformation temperature range and is at or below 75°C above the lower limit of the pearlite transformation temperature range.

3. The rail manufacturing method according to claim 1 or 2, which comprises allowing the rail after the end of accelerated cooling to be naturally cooled, and, after the temperature of the rail head surface falls to 200°C or below, cooling the rail at a rate of 1°C/s or more.

4. A rail having a bainite formation ratio of 15% or less in a region from a cooled surface of a rail head to a depth of 5 mm.

FIG. 1

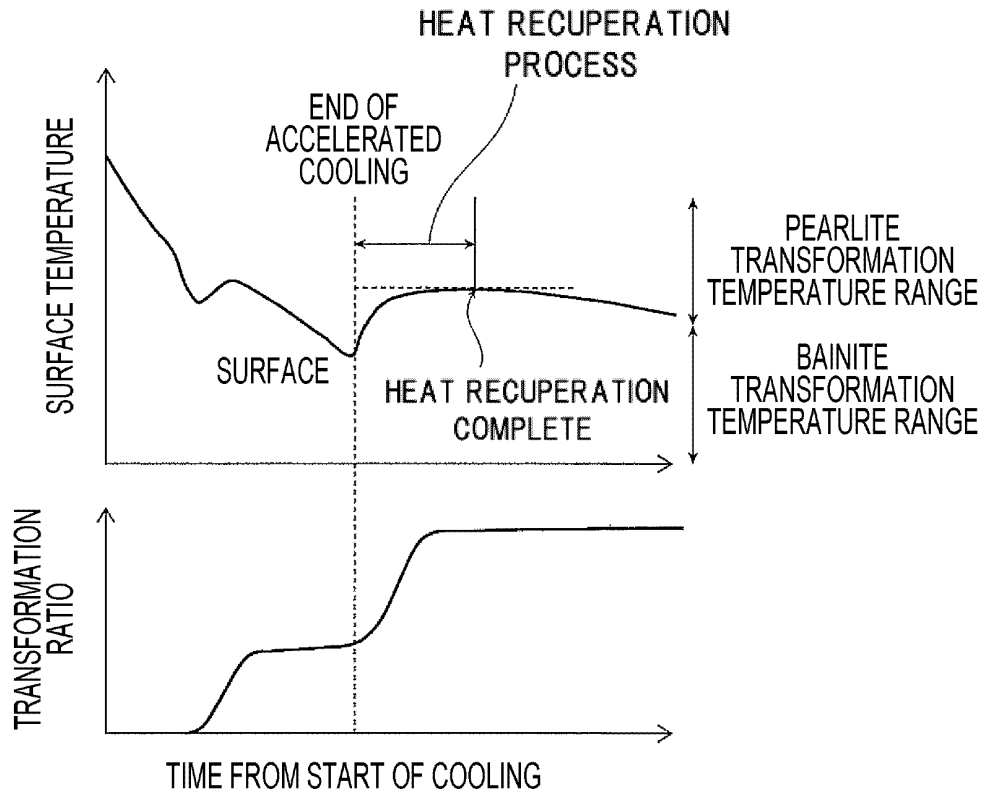


FIG. 2

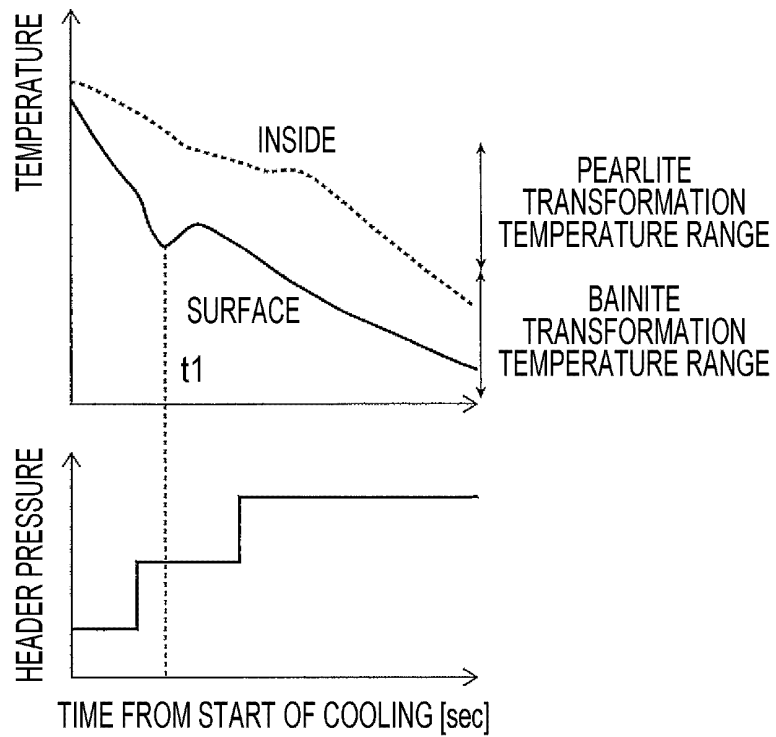
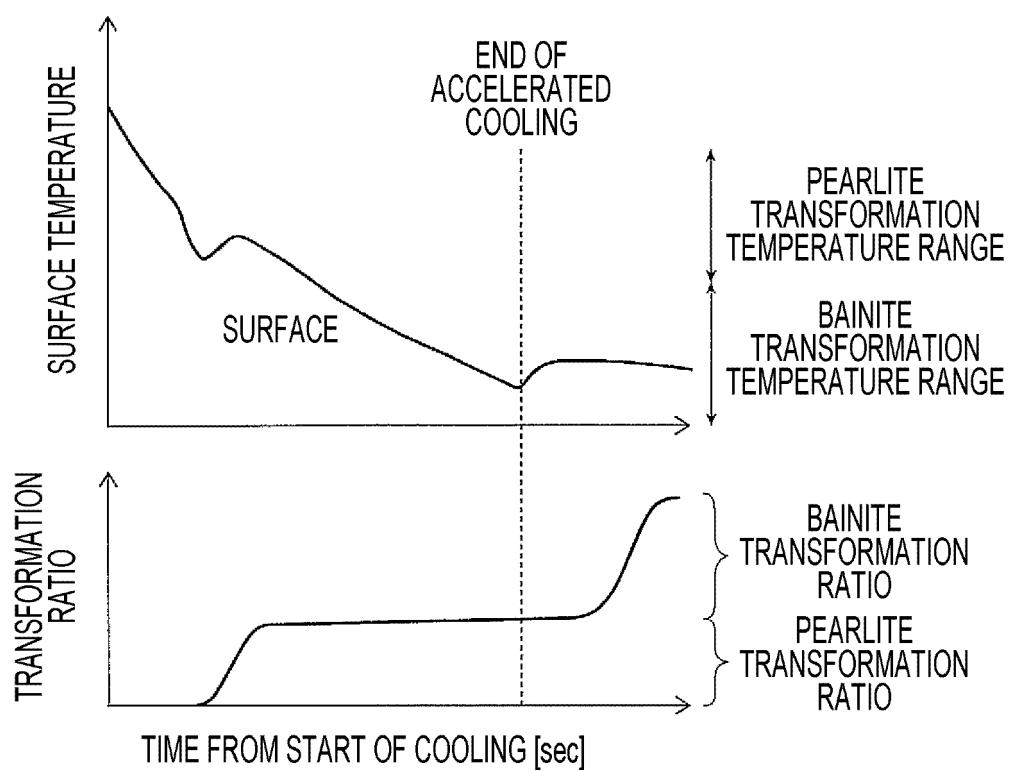


FIG. 3



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2022/004530

## A. CLASSIFICATION OF SUBJECT MATTER

C21D 8/00(2006.01)n; **C21D 9/04**(2006.01)i; C22C 38/00(2006.01)n; C22C 38/60(2006.01)n  
FI: C21D9/04 A; C21D8/00 A; C22C38/00 301Z; C22C38/60

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)

C21D8/00; C21D9/04; C22C38/00-C22C38/60

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

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

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

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                               | Relevant to claim No. |
|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| X         | JP 2001-20040 A (NIPPON STEEL CORP) 23 January 2001 (2001-01-23)<br>claims, paragraphs [0006], [0038]-[0046], [0048]-[0050], table 1, fig. 1-2   | 1-4                   |
| X         | JP 2003-129182 A (NIPPON STEEL CORP) 08 May 2003 (2003-05-08)<br>claims, paragraphs [0038], [0047]-[0049], table 1, fig. 1                       | 4                     |
| A         |                                                                                                                                                  | 1-3                   |
| X         | WO 2015/182759 A1 (NIPPON STEEL & SUMITOMO METAL CORP) 03 December 2015<br>(2015-12-03)<br>claims, paragraphs [0149]-[0151], [0170], tables 6, 8 | 4                     |
| A         |                                                                                                                                                  | 1-3                   |
| X         | US 2011/0253268 A1 (PANGANG GROUP CO., LTD.) 20 October 2011 (2011-10-20)<br>claims, paragraphs [0063]-[0076], tables 3-4                        | 4                     |
| A         |                                                                                                                                                  | 1-3                   |
| A         | JP 9-316598 A (NIPPON STEEL CORP) 09 December 1997 (1997-12-09)<br>entire text, all drawings                                                     | 1-4                   |

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

|                                                                                                                                                                         |                                                                                                                                                                                                                                                  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| * Special categories of cited documents:                                                                                                                                | "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention                                              |
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Date of the actual completion of the international search

08 April 2022

Date of mailing of the international search report

19 April 2022

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**INTERNATIONAL SEARCH REPORT**  
**Information on patent family members**

International application No.

**PCT/JP2022/004530**

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