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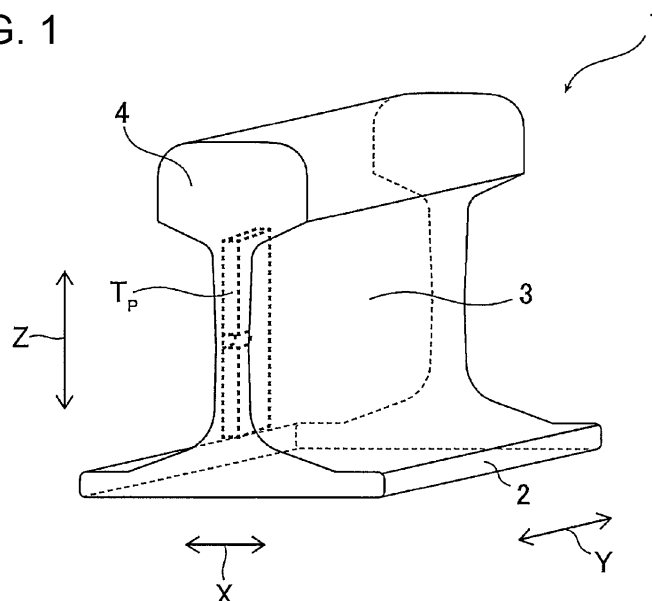
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(54) **RAIL AND METHOD FOR MANUFACTURING SAME**

(57) A rail 1 includes a foot 2, a web 3, and a head 4. The web 3 has a chemical composition containing C: 0.70 to 1.20 mass%, Si: 0.20 to 1.20 mass%, Mn: 0.20 to 1.50 mass%, P: 0.035 mass% or less, and Cr: 0.20 to

2.50 mass%, with the balance being Fe and incidental impurities. The area fraction of pearlite in the web 3 is 95% or more, and the average size of pearlite blocks is 60 μm or less.

FIG. 1



Description

Technical Field

5 **[0001]** The present invention relates to a railroad rail having a foot, a web, and a head and to a method for producing the rail.

Background Art

10 **[0002]** In heavy haul railroads mainly used to transport ore and other materials, the load on the axles of freight cars is much higher than that on the axles of passenger cars, and rails are used in harsh environments. The efficiency of transportation in railroads has been improved by further increasing the carrying capacity of freight cars. There is thus a need for improvements in wear resistance, fatigue damage resistance, and delayed fracture resistance.

15 **[0003]** There have been various proposes for improving the wear resistance and other properties of rails, such as controlling the materials of rails, or using a special heat treatment in the production method (e.g., see Patent Literature 1 to Patent Literature 8). Patent Literature 1 and Patent Literature 2 each disclose a rail with its wear resistance improved by increasing the C content to more than 0.85 mass% and 1.20 mass% or less. Patent Literature 3 and Patent Literature 4 each disclose a rail with its wear resistance improved by setting the C content to more than 0.85 mass% and 1.20 mass% or less and increasing the cementite fraction by heating the head of the rail.

20 **[0004]** Patent Literature 5 proposes a rail with its fatigue damage resistance improved by suppressing formation of pro-eutectoid cementite by addition of Al and Si. Patent Literature 6 discloses a rail with its service life improved by setting, to Hv 370 or higher, the Vickers hardness in a region from the surface of the corners and top of the head of the rail to a depth of at least 20 mm.

25 **[0005]** Patent Literature 7 discloses a method for forming a tempered martensite microstructure having high toughness in a web. The method includes rapidly cooling the web at a cooling rate of 15 °C/sec or higher, then stopping cooling at a temperature of 250 to 450°C, and when the bainite transformation reaches 30% or more, cooling the web to the Ms temperature or lower, forming a martensite microstructure. Patent Literature 8 discloses that the crack growth resistance of the web is provided by imparting compressive residual stress by cooling a rail from the top of the head to the upper neck or to the web with high pressure gas or water-containing gas.

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Citation List

Patent Literature

35 **[0006]**

PTL 1: Japanese Unexamined Patent Application Publication No. 8-109439

PTL 2: Japanese Unexamined Patent Application Publication No. 8-144016

PTL 3: Japanese Unexamined Patent Application Publication No. 8-246100

40 PTL 4: Japanese Unexamined Patent Application Publication No. 8-246101

PTL 5: Japanese Unexamined Patent Application Publication No. 2002-69585

PTL 6: Japanese Unexamined Patent Application Publication No. 10-195601

PTL 7: Japanese Unexamined Patent Application Publication No. 62-99438

PTL 8: Japanese Unexamined Patent Application Publication No. 59-47326

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Summary of Invention

Technical Problem

50 **[0007]** According to the rails in Patent Literature 1 to Patent Literature 6, the head of each rail which mainly come into contact with wheel flanges has high wear resistance. However, the materials of the web of the rail are not sufficiently controlled, and the web may undergo crack growth depending on production method.

[0008] The technique of Patent Literature 7 requires maintaining the temperature until bainite transformation starts, which reduces production efficiency. The technique disclosed in Patent Literature 8 puts the most importance on the wear resistance/fatigue damage resistance of the head and may not provide the web with desired crack growth resistance, and the martensite microstructure highly susceptible to cracking may be formed depending on production conditions.

55 **[0009]** The present invention has been made in light of the above circumstances. An object of the present invention is to provide a rail and a method for producing the rail in which rail breakage is prevented by suppressing web crack

growth while the production efficiency is improved. Solution to Problem

[0010] The present invention has been made to achieve the above object. The gist of the present invention is as described below.

[1] A rail includes a foot, a web, and a head,
wherein the web has a chemical composition containing:

C: 0.70 to 1.20 mass%,
Si: 0.20 to 1.20 mass%,
Mn: 0.20 to 1.50 mass%,
P: 0.035 mass% or less,
S: 0.0005 to 0.012 mass%, and
Cr: 0.20 to 2.50 mass%, with the balance being Fe and incidental impurities,
an area fraction of pearlite in the web is 95% or more, and
an average size of pearlite blocks is 60 μm or less.

[2] In the rail according to [1], the chemical composition further contains one or two or more selected from Cu: 1.0 mass% or less, Ni: 1.0 mass% or less, Nb: 0.05 mass% or less, Mo: 1.0 mass% or less and V: 0.005 to 0.10 mass%, W: 1.0 mass% or less, B: 0.005 mass% or less.

[3] In the rail according to [1] or [2], a crack growth rate da/dN (m/cycle) in the web at a stress intensity factor $\Delta K = 20 \text{ MPa}\cdot\text{m}^{1/2}$ is 8.0×10^{-8} or less.

[4] A rail production method for producing a rail from a slab having the chemical composition according to any one of [1] to [3] includes:

performing finish rolling at a finishing temperature of 1000°C or lower in such a manner that a reduction in area of the web is 10% or more; and
after finish rolling, cooling the web at a cooling rate of 1 to 5 °C/s from a temperature higher than or equal to a pearlite transformation start temperature to a temperature range of 400°C to 600°C.

[5] In the rail production method according to [4], wherein the finishing temperature in finish-rolling the web is in a range of 800°C to 900°C.

Advantageous Effects of Invention

[0011] According to the present invention, it is possible to reduce the crack growth rate in the web and thus to suppress the crack growth in the web and the breakage of the rail.

Brief Description of Drawings

[0012]

[Fig. 1] Fig. 1 is a perspective view of a rail according to a preferred embodiment of the present invention.

[Fig. 2] Fig. 2 is a plan view of the rail according to the preferred embodiment of the present invention.

[Fig. 3] Fig. 3 is a schematic view of an example rail production system used in a rail production method according to the present invention.

[Fig. 4] Fig. 4 is a schematic view of an example test specimen used in a web crack growth test.

Description of Embodiments

[0013] Embodiments of the present invention will be described below. Fig. 1 is a schematic view of a rail according to a preferred embodiment of the present invention. A rail 1 in Fig. 1 supports the load for passenger railroads or freight railroads and guides railroad cars in the running direction (direction of arrow Y). The rail 1 has a foot (bottom) 2, a web 3, and a head 4.

[0014] The foot 2 will be placed on railroad ties and has a cross section widening in the width direction (direction of arrow X). The web 3 has a shape extending vertically (direction of arrow Z) from the foot 2 and has a function of ensuring bending stiffness as a beam of the rail 1 itself. The head 4, which is located on the web 3, comes into contact with the wheels of trains and directly supports the load of the trains. As a train runs on the rail 1, the load from the wheels of the train is transmitted from the head 4 to the web 3 and from the web 3 to the foot 2.

[0015] Since the web 3 does not directly come into contact with the wheels unlike the head 4, the web 3 does not need to have wear resistance equivalent to that of the head 4. The web 3 transmits the wheel weight on the head 4 to the foot 2. When the wheel weight is applied eccentrically from the center of the head 4 in the width direction, the web 3 may undergo bending stress to cause horizontal cracks. For this, the web 3 needs to have high crack growth resistance.

The web 3 of the rail 1 thus has the following chemical composition and steel microstructure.

[0016] The rail 1 contains C: 0.70 to 1.20 mass%, Si: 0.20 to 1.20 mass%, Mn: 0.20 to 1.50 mass%, P: 0.035 mass% or less, S: 0.0005 to 0.012 mass%, and Cr: 0.20 to 2.50 mass%. The composition components will be described below separately.

C: 0.70 to 1.20 mass%

[0017] Carbon C is an essential element for ensuring the strength, or fatigue damage resistance, of a pearlite microstructure. The fatigue damage resistance increases as the C content increases. With a C content of less than 0.70 mass%, it is difficult to provide higher fatigue damage resistance than that of a conventional heat-treated type pearlite steel rail. With a C content of more than 1.20 mass%, considerable amount of pro-eutectoid cementite is formed at austenite grain boundaries during pearlite transformation after hot rolling, and the fatigue damage resistance remarkably decreases. Pro-eutectoid cementite is also found when the C content is 1.20 mass% or less, but it is formed in trace amounts. Pro-eutectoid cementite thus has a minor effect on the fatigue damage resistance. Therefore, the C content is 0.70 to 1.20 mass%. The C content is preferably 0.75 to 1.00 mass%. The C content is more preferably 0.75 to 0.85 mass%.

Si: 0.20 to 1.20 mass%

[0018] Silicon Si needs to be contained in an amount of 0.20 mass% or more to serve as a deoxidizer and an element that strengthens the pearlite microstructure. The presence of more than 1.20 mass% Si promotes generation of surface defects on rails. Therefore, the Si content is 0.20 to 1.20 mass%. The Si content is preferably 0.50 to 1.00 mass%.

Mn: 0.20 to 1.50 mass%

[0019] Manganese Mn is an element effective for maintaining high hardness inside the rail 1 since it has an effect of lowering the pearlite transformation temperature to make the interlamellar spacing fine. With a Mn content of less than 0.20 mass%, the above effect is not enough. With a Mn content of more than 1.50 mass%, a martensite microstructure tends to be formed, and hardening and brittleness tend to occur during heat treatment and welding to degrade material properties. Further, due to Mn increasing hardenability, more bainite microstructure is formed on the surface layer of an internal high hardness-type rail to degrade the wear resistance. Furthermore, addition of excess Mn lowers the pearlite equilibrium transformation temperature and decreases the degree of supercooling to make the interlamellar spacing coarse. Therefore, the Mn content is 0.20 to 1.50 mass%. The Mn content is preferably 0.40 to 1.20 mass%.

P: 0.035 mass% or less

[0020] The presence of more than 0.035 mass% P results in low ductility. Therefore, the P content is 0.035 mass% or less. The P content is preferably 0.020 mass% or less. If the P content is less than 0.001%, the steelmaking costs unavoidably increase. A P content of 0.001% or more is therefore acceptable.

S: 0.0005 to 0.012 mass%

[0021] Sulfur S is found in a steel material mainly in the form of A type inclusions. With a S content of more than 0.012 mass%, the amount of the inclusions significantly increases, and coarse inclusions are formed at the same time, which lowers the cleanliness of the steel material. To reduce the S content to less than 0.0005 mass%, the steelmaking costs increase. Therefore, the S content is 0.0005 to 0.012 mass%. The S content is preferably 0.0005 to 0.010 mass%. The S content is more preferably 0.0005 to 0.008 mass%.

Cr: 0.20 to 2.50 mass%

[0022] Chromium Cr is an element that raises the pearlite equilibrium transformation temperature to make the interlamellar spacing fine and also increases the strength through solid solution strengthening. However, enough internal hardness is not obtained with a Cr content of less than 0.20 mass%. Addition of more than 2.50 mass% Cr increases hardenability and tends to form a martensite microstructure. Moreover, under production conditions where no martensite

microstructure is formed, pro-eutectoid cementite is formed at prior austenite grain boundaries. This results in low wear resistance and low fatigue damage resistance. Therefore, the Cr content is 0.20 to 2.50 mass%. The Cr content is preferably 0.60 to 1.30 mass%.

[0023] In addition to these composition components, the chemical composition of the rail according to the present invention may further contains one or two or more selected from Cu: 1.0 mass% or less, Ni: 1.0 mass% or less, Nb: 0.05 mass% or less, Mo: 1.0 mass% or less and V: 0.005 to 0.10 mass%, W: 1.0 mass% or less, B: 0.005 mass% or less. The composition components will be described below separately.

Cu: 1.0 mass% or less

[0024] Copper Cu is an element that can further strengthen the steel through solid solution strengthening like Cr. The presence of more than 1.0 mass% Cu tends to cause Cu cracking. Therefore, when the chemical composition contains Cu, the Cu content is preferably 1.0 mass% or less. The Cu content is more preferably 0.005 to 0.5 mass%.

Ni: 1.0 mass% or less

[0025] Nickel Ni is an element that can strengthen the steel without degrading the ductility. When the rail 1 contains Cu, Ni is preferably added in combination with Cu because addition of Ni can prevent or reduce Cu cracking. If the Ni content exceeds 1.0 mass%, the steel hardenability further increases, and martensite tends to be formed, which results in low fatigue damage resistance and low fatigue damage resistance. Therefore, when Ni is contained, the Ni content is preferably 1.0 mass% or less. The Ni content is more preferably 0.005 to 0.5 mass%.

Nb: 0.05 mass% or less

[0026] Niobium Nb combines with C in the steel and precipitates as a carbide during and after hot rolling for forming a rail, which effectively reduces the prior austenite grain size. As a result, the fatigue damage resistance, the fatigue damage resistance, and the ductility are greatly improved to extend the service life of the rail. With a Nb content of more than 0.05 mass%, the effect of improving the wear resistance and the fatigue damage resistance is saturated, and the effect corresponding to an increase in content is not obtained. Therefore, the upper limit of the Nb content may be 0.05 mass%. With a Nb content of less than 0.001 mass%, it is difficult to obtain a sufficient effect of extending the service life of the rail. The presence of 0.001 mass% or more Nb provides an effect of extending the service life. Therefore, when Nb is contained, the Nb content is preferably 0.001 mass% or more. The Nb content is more preferably 0.001 mass% to 0.03 mass%.

Mo: 1.0 mass% or less

[0027] Molybdenum Mo is an element that can improve hardenability and can further strengthen the steel through solid solution strengthening. If the Mo content exceeds 1.0 mass%, martensite tends to be formed in the steel, which results in low wear resistance and low fatigue damage resistance. Therefore, when the chemical composition of the rail contains Mo, the Mo content is preferably 1.0 mass% or less. The Mo content is more preferably 0.005 to 0.5 mass%.

V: 0.005 to 0.10 mass%

[0028] Vanadium V is an element that forms a carbonitride and is dispersedly precipitated in the matrix to improve the fatigue damage resistance and the delayed fracture resistance. With a V content of less than 0.005 mass%, the above effect is not enough. The presence of more than 0.10 mass% V results in low workability and high alloy costs and thus increases the costs for producing the rail material. Therefore, the V content is 0.005 mass% to 0.10 mass% or less. The V content is preferably 0.01 to 0.08 mass%.

W: 1.0 mass% or less

[0029] Tungsten W is an element that precipitates as a carbide during and after hot rolling for forming a rail shape and improves the strength and ductility of the rail through precipitation strengthening. If the W content exceeds 1.0 mass%, martensite is formed in the steel, resulting in low ductility. Therefore, when W is added, the W content is preferably 1.0 mass% or less. The lower limit of the W content is not limited, but preferably 0.001 mass% or more in order to provide the effect of improving the strength and the ductility. The W content is more preferably 0.005 to 0.5 mass%.

B: 0.005 mass% or less

[0030] Boron B is an element that segregates at prior austenite grain boundaries and improves hardenability to improve the strength of the rail. If the B content exceeds 0.005 mass%, a martensite microstructure is formed, resulting in low wear resistance and low fatigue damage resistance. Therefore, when B is contained, the B content is preferably 0.005 mass% or less. The lower limit of the B content is not limited, but preferably 0.001 mass% or more in order to provide the effect of improving the strength and the ductility. The B content is more preferably 0.001 to 0.003 mass%.

[0031] The balance other than the above composition components in the rail 1 includes Fe and incidental impurities. Incidental impurities refer to impurities that are found in raw materials or incidentally incorporated during the production process and are basically unnecessary but allowed to be contained because they are found in trace amounts and do not affect the properties. Examples of incidental impurities include N and O. An N content of up to 0.0080 mass% is allowable, and an O content of up to 0.004 mass% is allowable. Titanium Ti forms an oxide and degrades the fatigue damage resistance, which is a fundamental feature of the rail, and the Ti content is thus preferably controlled at 0.0010 mass% or less.

<Steel Microstructure>

[0032] The web 3 of the rail 1 includes 95% or more area fraction of pearlite microstructure. The web 3 of the rail 1 may include trace amounts, or 5% or less in total, of bainite microstructure, martensite microstructure, pro-eutectoid cementite microstructure, and pro-eutectoid ferrite microstructure. The pearlite microstructure (pearlite blocks) is a lamellar microstructure composed of alternating layers of ferrite and cementite, and the pearlite blocks are composed of pearlite grains having the same orientation. There is a relationship between the pearlite microstructure and the crack growth, and the pearlite grain boundaries serve as a barrier to crack growth. If the web 3 includes less than 95% area fraction of pearlite microstructure, there is a shortage of pearlite grain boundaries for blocking crack growth. The web 3 of the rail 1 thus contains 95% or more area fraction of pearlite microstructure.

[0033] The pearlite blocks have an average size of 60 μm or less. There is also a relationship between the size of the pearlite blocks and the fatigue crack growth. As described above, the pearlite grain boundaries serve as a barrier to crack growth and block crack growth. When the pearlite blocks have a fine size, there is a high possibility that crack growth may pass through the grain boundaries having a crack growth retardation effect. This suppresses crack growth as a result. If the pearlite blocks have an average size of more than 60 μm , the crack growth retardation effect is not enough. For this, the average size of the pearlite blocks is 60 μm or less, preferably 40 μm or less.

<Rail Production System and Production Method>

[0034] Fig. 3 is a schematic view of an example rail production system. A rail production system 10 in Fig. 3 includes a BD (breakdown) rolling mill 11, rough rolling mills 12 and 13, a finish rolling mill 14, and a cooling facility 15. The BD rolling mill 11, the rough rolling mills 12 and 13, and the finish rolling mill 14 hot-roll a slab, and the cooling facility 15 cools the hot-rolled slab. The finish rolling mill 14 rolls the slab through, for example, a caliber rolling process. The finish rolling mill 14 has two upper and lower rolls with grooves according to a desired cross section and directly presses the web 3, the head 4, and the foot 2. The amounts of rolling reduction of the web 3, the head 4, and the foot 2 are controlled by adjusting the shapes of the grooves in the upper and lower rolls.

[0035] Next, the method for producing a rail will be described below with reference to Fig. 3. First, a slab SS (material slab) reheated in a heating furnace is rolled in the BD (breakdown) rolling mill 11 into an approximate shape of the rail 1. The slab SS rolled in the BD rolling mill 11 is hot-rolled in the rough rolling mills 12 and 13. Accordingly, the austenite grains coarsened by heating are repeatedly subjected to rolling and recrystallization in a recrystallization temperature range in the BD rolling mill 11 and the rough rolling mills 12 and 13 to form fine grains.

[0036] Next, the slab SS is hot-rolled in finish rolling in the finish rolling mill 14 in such a manner that the finishing temperature of the web 3 is 1000°C or lower and the reduction in area of the web 3 is 10% or more. The finishing temperature refers to the surface temperature of the web 3 during finish rolling, but the surface temperature of the head 4 may be regarded as the finishing temperature of the web 3.

[0037] When the slab SS is rolled in a non-recrystallization temperature range (low temperature range), such as 1000°C or lower, in which recrystallization is unlikely to occur, the austenite grains are elongated without being recrystallized, and deformation bands are formed in the grains. During transformation from austenite to pearlite, the deformation bands in the grains serve as nucleation sites for pearlite transformation together with austenite grain boundaries. The pearlite grains become finer accordingly. At a finishing temperature above the recrystallization temperature range, recovery by recrystallization occurs, and the average size of the pearlite blocks cannot be reduced to 60 μm or less. To make the crystal grains finer by rolling in a non-recrystallization temperature range (low temperature range), the finishing temperature during finish rolling is set to 1000°C or lower, which is a non-recrystallization temperature range (low

temperature range). If the finishing temperature is below 800°C, a significantly large load is applied to the rolls during rolling. In addition, rolling in an austenite low temperature range introduces remarkable working strain into the austenite grains, so that a desired crack growth retardation effect cannot be obtained as a result. Therefore, the finishing temperature is preferably 800°C to 900°C during finish rolling.

[0038] To make the pearlite blocks finer, it is necessary to press the web 3 to induce strain. The slab SS is thus finish-rolled in the finish rolling mill 14 in such a manner that the reduction in area of the web 3 is 10% or more. The reduction in area is expressed by reduction in area (%) = $((A1 - A2)/A1) \times 100$, where A1 represents the cross-sectional area before finish rolling, and A2 represents the cross-sectional area after finish rolling. If the reduction in area is less than 10%, the average size of the pearlite blocks cannot be reduced to 60 μm or less, and the crack growth retardation effect cannot be obtained. The reduction in area is more preferably 30% or more.

[0039] After finish rolling in the finish rolling mill 14, the web 3 of the rail is subjected to accelerated cooling in the cooling facility 15 at a cooling rate of 1 to 5 °C/s from a temperature higher than or equal to a pearlite transformation start temperature to a temperature range of 400°C to 600°C. The cooling stop temperature refers to, for example, the surface temperature at a central portion of the rail web 4 measured with a radiation thermometer when cooling is stopped. The cooling rate (°C/sec) refers to a temperature change per unit time (sec) from cooling start to cooling stop.

[0040] At a cooling rate higher than 5 °C/s, the area fraction of pearlite microstructure decreases and the area fraction of martensite microstructure and other microstructures increases, so that the pearlite microstructure cannot occupy 95% or more area fraction. Accelerated cooling at a cooling rate of 1 to 5 °C/s can form the web 3 composed of pearlite and containing 95% or more area fraction of pearlite microstructure. In addition, the production efficiency can be improved because there is no need to maintain the temperature until bainite transformation starts unlike a conventional manner.

EXAMPLE 1

[0041] The structure and operational effects of the present invention will be more specifically described below by way of Example. The present invention is not limited by the following Example and can be appropriately modified within the range of the spirit of the present invention. All of the modifications are included in the technical scope of the present invention.

<Preparation of Test Specimens>

[0042] First, steels A1 to A15 and B1 to B6, which have different chemical compositions, are prepared. Table 1 below shows the components of the steels A1 to A15 and B1 to B6. The blanks in Table 1 mean that the component is absent or negligible because of the content being in the range of incidental impurities.

[Table 1]

Steel No.	Chemical Composition (mass%)													Note
	C	Si	Mn	P	S	Cr	Cu	Ni	Nb	Mo	V	W	B	
A1	0.71	0.81	0.63	0.014	0.004	1.35								Invention Example
A2	0.82	0.65	1.02	0.011	0.006	1.15								Invention Example
A3	0.94	0.23	0.92	0.011	0.012	0.95								Invention Example
A4	0.99	0.58	0.24	0.010	0.005	0.35								Invention Example
A5	1.08	1.05	0.78	0.010	0.010	0.57								Invention Example
A6	1.12	1.16	0.42	0.010	0.009	1.03								Invention Example
A7	1.18	0.77	1.46	0.010	0.005	0.21								Invention Example
B1	0.65	0.42	1.15	0.014	0.008	0.40								<u>Comparative Example</u>
B2	<u>1.22</u>	0.84	0.86	0.014	0.005	1.51								<u>Comparative Example</u>
B3	1.01	<u>0.18</u>	0.24	0.012	0.006	0.65								<u>Comparative Example</u>
B4	0.83	0.63	<u>1.53</u>	0.011	0.011	0.60								<u>Comparative Example</u>
B5	0.75	0.77	1.42	0.014	0.010	0.19								<u>Comparative Example</u>
A8	0.81	0.75	0.68	0.015	0.005	1.23	0.89							Invention Example
A9	1.03	0.66	1.01	0.012	0.006	1.06		0.85						Invention Example
A10	1.10	0.25	0.94	0.013	0.003	0.93			0.04					Invention Example
A11	1.18	0.53	0.21	0.009	0.004	0.36				0.82		0.76		Invention Example
A12	0.75	0.93	0.44	0.014	0.005	0.45					0.08			Invention Example
A13	0.92	0.31	0.63	0.012	0.011	0.64	0.77					0.91		Invention Example
A14	0.85	0.78	0.84	0.011	0.009	0.87			0.03				0.004	Invention Example
A15	0.84	0.25	0.21	0.010	0.005	2.49								Invention Example
B6	0.91	0.56	0.36	0.011	0.008	2.52								<u>Comparative Example</u>

[0043] Next, rails (No. 1 to No. 25 in Table 2 below) were produced in the rail production system 10 in Fig. 3 under predetermined production conditions using the steels A1 to A15 and B1 to B6 containing the composition components in Table 1. Subsequently, steel materials were extracted from the webs 3 of the produced rails 1 to prepare test specimens. Fig. 4 is a schematic view of an example test specimen. In Fig. 4, the test specimen has, for example, a plate shape with width $W = 20$ mm, length $H = 100$ mm, and thickness $B = 5$ mm. The test specimen has a notch at a half $H/2$ of the height H . The notch has length $L = 2$ mm and width $C = 0.2$ mm. The end of the notch has curvature radius $R = 0.1$ mm.

[0044] Table 2 shows the rail production conditions and the test results.

[Table 2]

Rail No.	Steel No.	Production Conditions		Web Microstructure *1	Block Size (μm)	Crack Growth Rate da/dN at $\Delta K = 20$ $\text{MPa}\cdot\text{m}^{1/2}$ ($\times 10^{-8}$ m/cycle)	Note
		Reduction(%) in Area of Web at 1000°C or Lower	Web Cooling Rate ($^{\circ}\text{C}/\text{sec}$)				
1	A1-1	10	4	P	59	7.7	Invention Example
2	A2-1	25	3	P	48	5.2	Invention Example
3	A3-1	30	5	P	38	6.5	Invention Example
4	A4-1	40	1	P	17	3.1	Invention Example
5	A5-1	15	2	P	52	7.9	Invention Example
6	A6-1	20	3	P	47	4.8	Invention Example
7	A7-1	35	4	P	30	3.8	Invention Example
8	A1-2	5	3	P	68	<u>8.2</u>	Comparative Example
9	A3-2	8	3	P	61	<u>9.2</u>	Comparative Example
10	A4-2	25	6	<u>P+M</u>	50	<u>10.3</u>	Comparative Example
11	A5-2	0	3	P	74	<u>8.9</u>	Comparative Example
12	<u>B1-1</u>	30	5	P	54	<u>11.2</u>	Comparative Example
13	<u>B2-1</u>	15	4	<u>P+0</u>	30	<u>12.1</u>	Comparative Example
14	<u>B3-1</u>	20	3	P	25	<u>8.5</u>	Comparative Example
15	<u>B4-1</u>	35	2	<u>P+M</u>	31	<u>9.4</u>	Comparative Example
16	<u>B5-1</u>	10	4	P	58	<u>9.1</u>	Comparative Example
17	A8-1	12	3	P	55	6.9	Invention Example

(continued)

Rail No.	Steel No.	Production Conditions		Web Microstructure *1	Block Size (μm)	Crack Growth Rate da/dN at $\Delta K = 20 \text{ MPa}\cdot\text{m}^{1/2}$ ($\times 10^{-8} \text{ m/cycle}$)	Note
		Reduction(%) in Area of Web at 1000°C or Lower	Web Cooling Rate ($^{\circ}\text{C/sec}$)				
18	A9-1	26	5	P	38	5.6	Invention Example
19	A10-1	32	2	P	28	6.0	Invention Example
20	A11-1	42	3	P	17	4.2	Invention Example
21	A12-1	18	4	P	52	7.8	Invention Example
22	A13-1	22	1	P	47	5.5	Invention Example
23	A14-1	35	4	P	30	4.9	Invention Example
24	A15-1	25	2	P	45	6.8	Invention Example
25	B6-1	20	1	P+ θ	39	10.9	Comparative Example
*1: Microstructure: P $\rightarrow$ pearlite, M $\rightarrow$ martensite, θ $\rightarrow$ cementite "P" indicates that the area fraction of pearlite is 95% or more, and "P + M" and "P + θ " indicate that the area fraction of pearlite is less than 95%.							

<Evaluation Method>

[0045] A fatigue crack growth test was conducted at a stress ratio $R = 0.1$ using the test specimen in Fig. 4, and the fatigue crack growth rate da/dN (m/cycle) was measured at a stress intensity factor $\Delta K = 20 \text{ MPa}\cdot\text{m}^{1/2}$ to evaluate the surface damage resistance of the web. When the fatigue crack growth rate was 8.0×10^{-8} or less, the web was determined to have crack growth resistance.

[0046] In the production conditions in Table 2, the finishing temperature is obtained by measuring the surface temperature of the web 3 at the inlet of the finish rolling mill 14 using a radiation thermometer, and the cooling stop temperature is obtained by measuring the surface temperature of the web 3 using a radiation thermometer when cooling is stopped.

[0047] The size of the pearlite blocks in Table 2 was obtained as follows: a test specimen for microscopic observation of L cross sections was sampled at a middle point of the rail web, embedded followed by mirror polishing, and then subjected to orientation analysis using an EBSD (electron backscatter diffraction pattern), and the sizes of pearlite grains of respective orientations were measured as equivalent circular diameters and averaged. The grain boundaries at which a difference in orientation between adjacent crystal orientations was 5° or more were determined to define different pearlite blocks. The measurement region was $300 \mu\text{m}$ square, the step size was $0.3 \mu\text{m}$, and measurement points at which the Confidence index indicating the reliability of measured orientation was 0.1 or less were removed from analysis targets. Crystal grains on the edges of the measurement region were also removed from analysis targets.

[0048] In Table 2, "P" means that the web includes 95% or more area fraction of pearlite microstructure, and trace amounts, or 5% or less in total, of bainite microstructure, martensite microstructure, pro-eutectoid cementite microstructure, and pro-eutectoid ferrite microstructure. The area fraction of pearlite microstructure can be measured by using a known technique. For example, the sampled test specimen is polished and then etched in nital, the type of microstructure is identified through cross-sectional observation using an optical microscope at a magnification of 400 times, and the area fraction of pearlite microstructure is calculated by image analysis.

[0049] Rails No. 1 to No. 7 and No. 24 were produced by using compatible steels that satisfy the mass percentages of the component composition of the present invention in accordance with production methods that satisfy the finish rolling conditions and the cooling conditions. The area fraction of pearlite in each of the webs 3 was 95% or more, and

the average size of pearlite blocks was 60 μm or less. As a result, the crack growth rate da/dN (m/cycle) in each of the webs 3 at a stress intensity factor $\Delta K = 20 \text{ MPa}\cdot\text{m}^{1/2}$ was 8.0×10^{-8} or less. In addition, the crack growth rate da/dN (m/cycle) in the web 3 was 8.0×10^{-8} or less even when a predetermined mass% of at least one of Cu, Ni, Nb, Mo, V, W, and B was contained as in No. 17 to No. 23 (Steel No. A8 to No. A14).

[0050] When the reduction in area in finish rolling is less than 10% as in No. 8 and No. 9, the average size of pearlite blocks is larger than 60 μm . As a result, the crack growth rate da/dN (m/cycle) in the web 3 does not satisfy 8.0×10^{-8} or less.

[0051] When the cooling rate after finish rolling is higher than 5 °C/sec as in No. 10, the area fraction of martensite microstructure is high, and the area fraction of pearlite microstructure in the web 3 is less than 95%. As a result, the crack growth rate da/dN (m/cycle) in the web 3 does not satisfy 8.0×10^{-8} or less.

[0052] When, as in No. 11 to No. 16 and No. 25, steels are out of the range of the mass percentages of the chemical composition according to the present invention, even when the temperature conditions and the reduction in area in finish rolling and the cooling rate satisfy the conditions defined in the present invention, the area fraction of pearlite microstructure in the web 3 is less than 95%, or the average size of pearlite blocks is larger than 60 μm . As a result, the crack growth rate da/dN (m/cycle) in the web does not satisfy 8.0×10^{-8} or less.

[0053] According to the present invention, the microstructure of the web 3 of the rail 1 is controlled by controlling the components of the steel, the finish rolling conditions, and the cooling conditions to lower the web crack growth rate in the web 3 of the rail 1 and thus to suppress the crack growth in the web 3 and the breakage of the rail.

[0054] The embodiment of the present invention is not limited to the above embodiment, and various modifications can be made to the embodiment of the present invention. For example, the conditions for producing the web 3 are illustrated in the embodiment, in which the foot 2 and the head 4 are hot-rolled at the same time when the web 3 is hot-rolled. There, for example, a rail 1 may be produced by preparing a slab having chemical compositions that satisfy the performance requirements for both the web 3 and the head 4, and hot rolling and cooling the web 3 and the head 4 under different conditions such that both the crack growth resistance of the web 3 and the wear resistance of the head 4 and other properties are satisfied.

Reference Signs List

[0055]

1	Rail
2	Foot (bottom)
3	Web
4	Head
10	Rail production system
11	BD rolling mill
12, 13	Rough rolling mill
14	Finish rolling mill
15	Cooling facility
SS	Slab

Claims

1. A rail comprising a foot, a web, and a head,
wherein the web has a chemical composition comprising:

C: 0.70 to 1.20 mass%,
Si: 0.20 to 1.20 mass%,
Mn: 0.20 to 1.50 mass%,
P: 0.035 mass% or less,
S: 0.0005 to 0.012 mass%, and
Cr: 0.20 to 2.50 mass%, with the balance being Fe and incidental impurities,
an area fraction of pearlite in the web is 95% or more, and
an average size of pearlite blocks is 60 μm or less.

2. The rail according to Claim 1, wherein the chemical composition further comprises one or two or more selected from Cu: 1.0 mass% or less, Ni: 1.0 mass% or less, Nb: 0.05 mass% or less, Mo: 1.0 mass% or less and V: 0.005 to

0.10 mass%, W: 1.0 mass% or less, B: 0.005 mass% or less.

3. The rail according to Claim 1 or 2, wherein a crack growth rate da/dN (m/cycle) in the web at a stress intensity factor $\Delta K = 20 \text{ MPa}\cdot\text{m}^{1/2}$ is 8.0×10^{-8} or less.

4. A rail production method for producing a rail from a slab having the chemical composition according to any one of Claims 1 to 3, the method comprising:

performing finish rolling at a finishing temperature of 1000°C or lower in such a manner that a reduction in area of the web is 10% or more; and
after finish rolling, cooling the web at a cooling rate of 1 to 5 °C/s from a temperature higher than or equal to a pearlite transformation start temperature to a temperature range of 400°C to 600°C.

5. The rail production method according to Claim 4,
wherein the finishing temperature in finish-rolling the web is in a range of 800 to 900°C.

FIG. 1

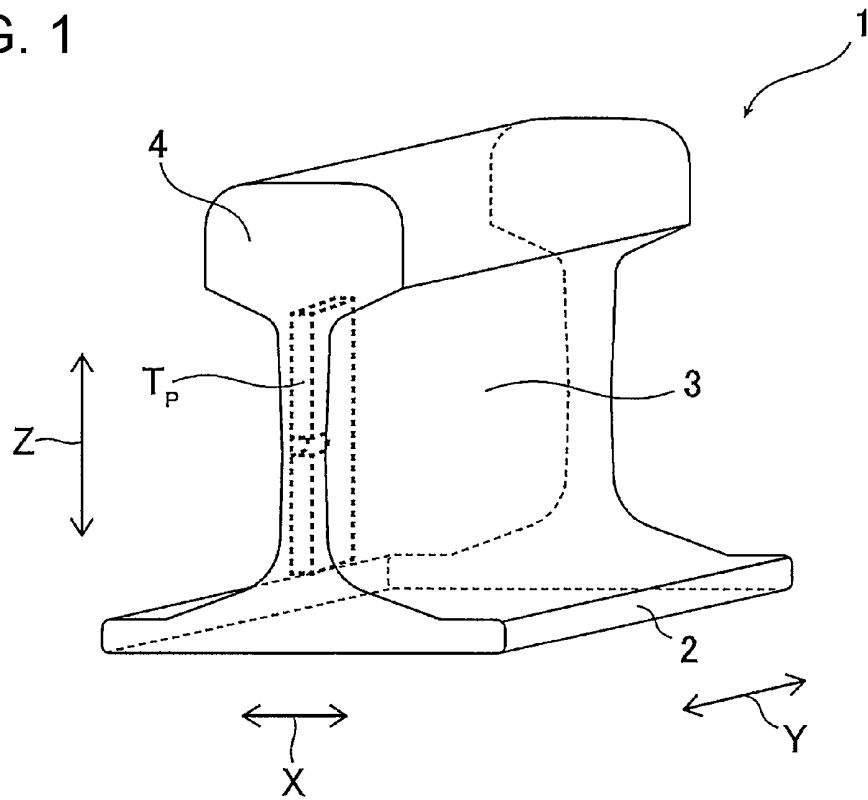


FIG. 2

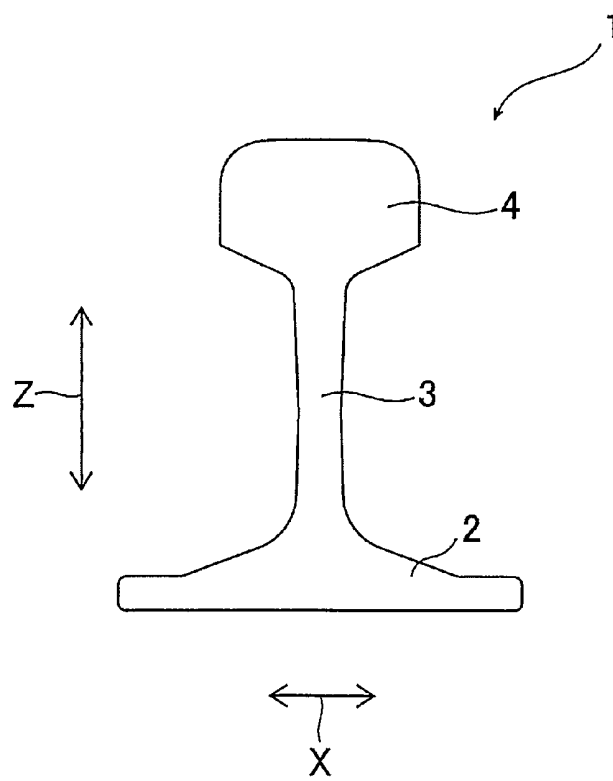


FIG. 3

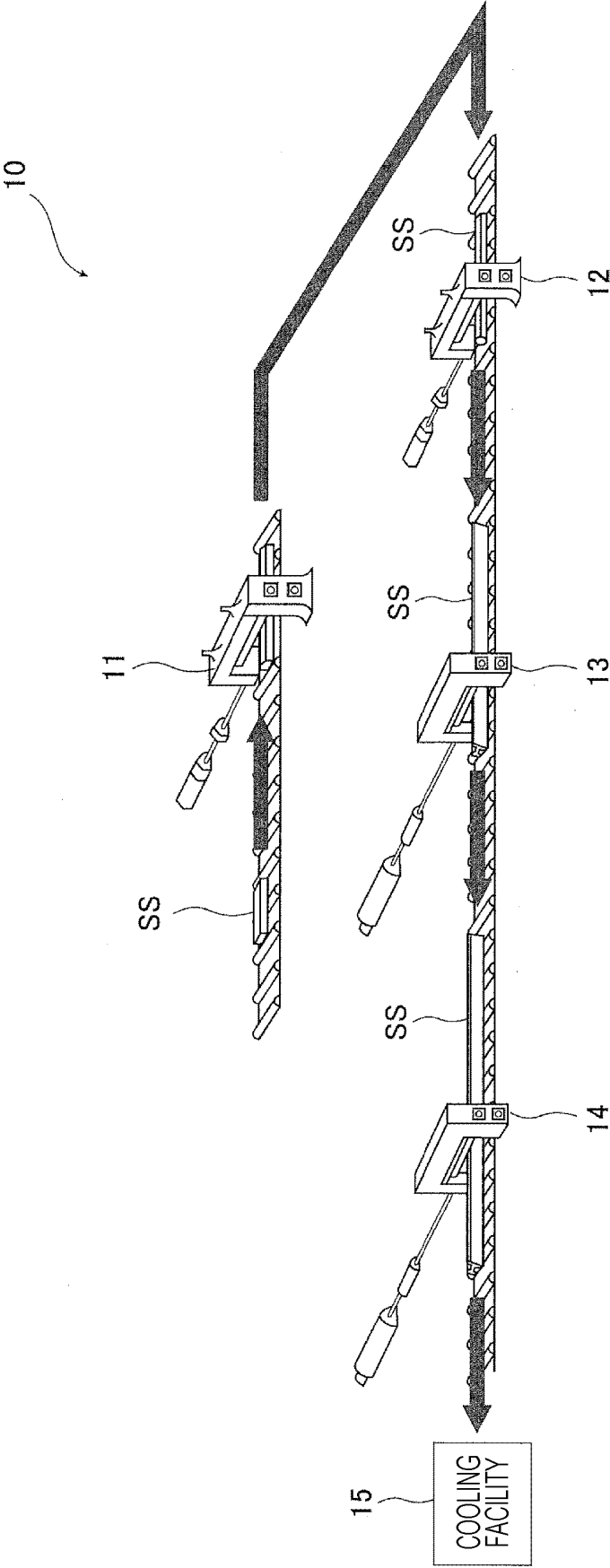
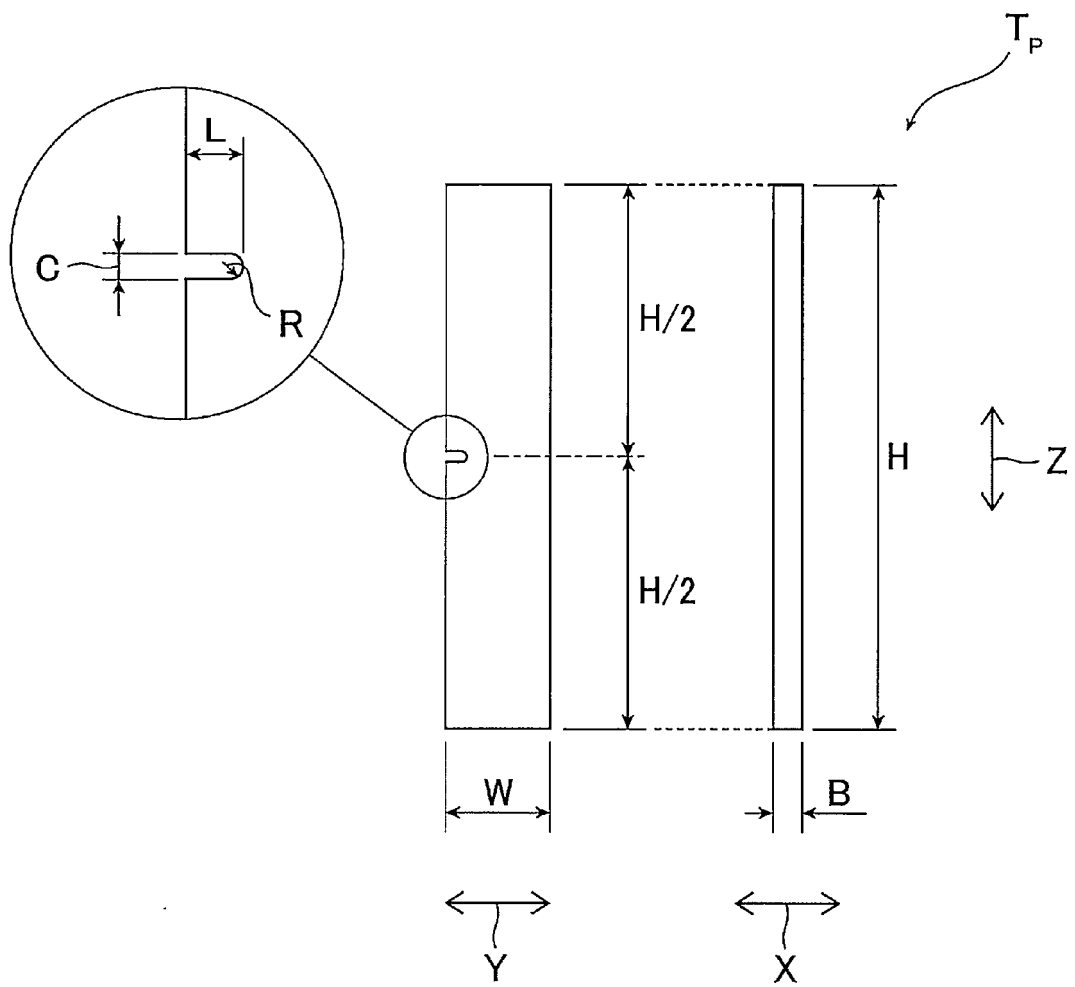


FIG. 4



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2020/028616

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. C21D8/00(2006.01)i, C22C38/00(2006.01)i, C22C38/18(2006.01)i, C22C38/54(2006.01)i

FI: C22C38/00301Z, C22C38/18, C21D8/00B, C22C38/54

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. 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 1971-2020

Registered utility model specifications of Japan 1996-2020

Published registered utility model applications of Japan 1994-2020

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 A	JP 8-109440 A (NIPPON STEEL CORPORATION) 30.04.1996 (1996-04-30), claims, paragraphs [0001]-[0009], [0017], [0019]-[0024], tables 1-4	1-4 5
Y	JP 2004-162106 A (NIPPON STEEL CORPORATION) 10.06.2004 (2004-06-10), claims, paragraphs [0001]-[0009], [0021]-[0034], tables 1, 2	1-5
Y	JP 8-109439 A (NIPPON STEEL CORPORATION) 30.04.1996 (1996-04-30), claims, paragraphs [0001]-[0005], [0019], [0021]-[0026], tables 1-4	1-5
A	JP 2004-43863 A (NIPPON STEEL CORPORATION) 12.02.2004 (2004-02-12), entire text, all drawings	1-5
A	JP 2002-363702 A (NIPPON STEEL CORPORATION) 18.12.2002 (2002-12-18), entire text, all drawings	1-5
A	US 2016/0194729 A1 (PANGANG GROUP PANZHIHUA IRON & STEEL RESEARCH INSTITUTE CO., LTD.) 07.07.2016 (2016-07-07), entire text, all drawings	1-5



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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
01.10.2020Date of mailing of the international search report
13.10.2020Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, JapanAuthorized officer

Telephone No.

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/JP2020/028616

JP 8-109440 A	30.04.1996	US 5658400 A claims, column 1, lines 6 to column 2, line 35, column 4, lines 22-26, column 6, lines 18-37, tables 1-4 WO 1995/017532 A1 EP 685566 A1 DE 69427189 T2 AU 1201395 A BR 9406250 A CA 2154779 A1 RU 2107740 C1 AT 201054 T KR 10-0186793 B1 CN 1118174 A
JP 2004-162106 A	10.06.2004	US 2004/0187981 A1 claims, paragraphs [0001]-[0016], [0159]-[0212], [0316], [0317], tables 11-13 WO 2003/085149 A1 EP 1493831 A1 CA 2451147 A1 BR 304718 A HK 1068926 A1 CN 1522311 A AU 2003236273 A1
JP 8-109439 A	30.04.1996	US 5658400 A claims, column 1, line 6 to column 2, line 35, column 4, lines 22-26, column 6, lines 18-37, tables 1-4 WO 1995/017532 A1 EP 685566 A1 DE 69427189 T2 AU 1201395 A BR 9406250 A CA 2154779 A1 RU 2107740 C1 AT 201054 T KR 10-0186793 B1 CN 1118174 A

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2020/028616

5	JP 2004-43863 A	12.02.2004	US 2004/0187981 A1 entire text, all drawings WO 2003/085149 A1 EP 1493831 A1 CA 2451147 A1 BR 304718 A HK 1068926 A1 CN 1522311 A AU 2003236273 A1
10			
15	JP 2002-363702 A	18.12.2002	(Family: none)
	US 2016/0194729 A1	07.07.2016	CN 104561816 A entire text, all drawings AU 2016200056 A1
20			
25			
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35			
40			
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Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 8109439 A [0006]
- JP 8144016 A [0006]
- JP 8246100 A [0006]
- JP 8246101 A [0006]
- JP 2002069585 A [0006]
- JP 10195601 A [0006]
- JP 62099438 A [0006]
- JP 59047326 A [0006]