Office de la Propriété
Intellectuelle
du Canada

Un organisme
d'Industrie Canada

Canadian
Intellectual Property
Office

An agency of
Industry Canada

CA 2936780 A1 2015/10/01

(21) **2 936 780**

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) **A1**

(86) **Date de dépôt PCT/PCT Filing Date:** 2015/03/24
(87) **Date publication PCT/PCT Publication Date:** 2015/10/01
(85) **Entrée phase nationale/National Entry:** 2016/07/13
(86) **N° demande PCT/PCT Application No.:** JP 2015/001659
(87) **N° publication PCT/PCT Publication No.:** 2015/146150
(30) **Priorité/Priority:** 2014/03/24 (JP2014-060786)

(51) **Cl.Int./Int.Cl.** ***C22C 38/00*** (2006.01), ***C21D 8/00*** (2006.01), ***C21D 9/04*** (2006.01), ***C22C 38/18*** (2006.01), ***C22C 38/46*** (2006.01)

(71) **Demandeur/Applicant:**
JFE STEEL CORPORATION, JP

(72) **Inventeurs/Inventors:**
KIMURA, TATSUMI, JP;
TAKASHIMA, YUKIO, JP

(74) **Agent:** ROBIC

(54) **Titre : RAIL ET PROCEDE POUR LE FABRIQUER**
(54) **Title: RAIL AND METHOD FOR MANUFACTURING SAME**

(57) **Abrégé/Abstract:**

Provided is a rail which has reduced fluctuations in hardness as measured in the length direction of the rail and also has ensured excellent wear resistance. A rail which has a chemical composition comprising 0.60 to 1.0% of C, 0.1 to 1.5% of Si, 0.01 to 1.5% of Mn, 0.035% or less of P, 0.030% or less of S, 0.1 to 2.0% of Cr, and a remainder made up by Fe and unavoidable impurities, wherein the fluctuations in surface hardness of the rail as measured in the length direction of the rail fall within the range of ± HB15 points or smaller.

(12) 特許協力条約に基づいて公開された国際出願

(19) 世界知的所有権機関
国際事務局

(43) 国際公開日
2015 年 10 月 1 日(01.10.2015)

(10) 国際公開番号
WO 2015/146150 A1

(51) 国際特許分類:
C22C 38/00 (2006.01)
C22C 38/18 (2006.01)
C21D 8/00 (2006.01)
C22C 38/46 (2006.01)
C21D 9/04 (2006.01)

(21) 国際出願番号: PCT/JP2015/001659

(22) 国際出願日: 2015 年 3 月 24 日(24.03.2015)

(25) 国際出願の言語: 日本語

(26) 国際公開の言語: 日本語

(30) 優先権データ:
特願 2014-060786 2014 年 3 月 24 日(24.03.2014) JP

(71) 出願人: ＪＦＥスチール株式会社 (**JFE STEEL CORPORATION**) [JP/JP]; 〒1000011 東京都千代田区内幸町二丁目２番３号 Tokyo (JP).

(72) 発明者: 木村 達己 (**KIMURA, Tatsumi**); 〒1000011 東京都千代田区内幸町二丁目２番３号 ＪＦＥスチール株式会社 知的財産部内 Tokyo (JP). 高嶋 由紀雄 (**TAKASHIMA, Yukio**); 〒1000011 東京都千代田区内幸町二丁目２番３号 ＪＦＥスチール株式会社 知的財産部内 Tokyo (JP).

(74) 代理人: 杉村 憲司 (**SUGIMURA, Kenji**); 〒1000013 東京都千代田区霞が関三丁目２番１号 霞が関コモンゲート西館３６階 Tokyo (JP).

(81) 指定国 (表示のない限り、全ての種類の国内保護が可能): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) 指定国 (表示のない限り、全ての種類の広域保護が可能): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), ユーラシア (AM, AZ, BY, KG, KZ, RU, TJ, TM), ヨーロッパ (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

添付公開書類:
— 国際調査報告（条約第 21 条(3)）

WO 2015/146150 A1

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

(54) 発明の名称 : レールおよびその製造方法

(57) **Abstract**: Provided is a rail which has reduced fluctuations in hardness as measured in the length direction of the rail and also has ensured excellent wear resistance. A rail which has a chemical composition comprising 0.60 to 1.0% of C, 0.1 to 1.5% of Si, 0.01 to 1.5% of Mn, 0.035% or less of P, 0.030% or less of S, 0.1 to 2.0% of Cr, and a remainder made up by Fe and unavoidable impurities, wherein the fluctuations in surface hardness of the rail as measured in the length direction of the rail fall within the range of ± HB15 points or smaller.

(57) 要約: レール長さ方向の硬さのばらつきを抑制して優れた耐摩耗性を確保したレールを提供する。Ｃ：0.60～1.0%、Si：0.1～1.5%、Mn：0.01～1.5%、Ｐ：0.035%以下、Ｓ：0.030%以下および Cr：0.1～2.0% を含有し、残部が Fe および不可避的不純物の成分組成を有するレールであって、該レール長さ方向の表面硬さのばらつきを±HB15 ポイント以下とする。

RAIL AND METHOD FOR MANUFACTURING SAME

TECHNICAL FIELD

[0001] The present disclosure relates to a rail, particularly a rail having high hardness and small hardness variation, and also to a method for manufacturing the rail.

BACKGROUND

[0002] Freight cars used on freight transportation and mining railways tend to have heavier loading weights than passenger cars, which results in heavy loads acting on the axles of the freight cars and a severe contact environment between the freight car wheels and rails. Rails used under these conditions are expected to exhibit wear resistance and are conventionally made from steel having a pearlite structure.

[0003] In recent years, there has been a trend toward even heavier loading weights of freight, minerals, and so forth in order to improve railway transport efficiency, which has led a further increase in rail wear and a decrease in rail service life. Accordingly, there is demand for improved rail wear resistance in order to extend rail service life and numerous high hardness rails have been proposed in which rail hardness is enhanced.

For example, PTL 1, PTL 2, PTL 3, and PTL 4 each disclose a hypereutectoid rail having increased cementite content and a manufacturing method thereof. Moreover, PTL 5, PTL 6, and PTL 7 each disclose a technique for increasing hardness by refining the lamellar spacing of a pearlite structure in steel containing the eutectoid level of carbon content.

[0004] With regards to a method for manufacturing a rail, PTL 8 proposes a method for manufacturing a high hardness rail having superior head internal fatigue resistance. In rolling of a rail steel slab in this method, finish rolling is performed at a head surface temperature of 850°C to 1050°C to leave final finishing, and after a time interval between passes of at least 3 seconds and no greater than 1 minute, one pass or a plurality of passes of final finish rolling are performed at a head surface temperature of 800°C to 950°C and with a rolling reduction of 10% or less per pass. Thereafter, accelerated cooling is started at a cooling rate of 2°C/s to 4°C/s for 0.1 seconds to 10 seconds to cool the temperature at less than 5 mm from the surface of the head and corner of the rail to the Ar_1 transformation temperature or lower, and cooling is continued at a maximum surface cooling rate of at least 4°C/s and no greater than 30°C/s.

[0005] PTL 9 describes a method for manufacturing a high toughness rail that exhibits a pearlite metal structure. In this method, after rough rolling of a steel slab of low-alloy steel or carbon steel containing 0.60% to 1.00% of C into a rail shape, continuous finish rolling is performed for three or more rolling passes at a rail surface temperature of 850°C to 1000°C with a cross-section area reduction rolling reduction of 5% to 30% per pass and 10 seconds or less between rolling passes, and thereafter the rail is allowed to cool or is cooled from 700°C or higher to a temperature in a range of 500°C to 700°C at a rate of 2°C/s to 15°C/s.

[0006] Furthermore, PTL 10 discloses a method for manufacturing a pearlitic rail having superior wear resistance and ductility in which at least rough rolling and finish rolling are performed on a steel slab for rail rolling that contains, in mass%, 0.65% to 1.20% of C, 0.05% to 2.00% of Si, and 0.05% to 2.00% of Mn, the balance being Fe and incidental impurities. In the finish rolling, rolling is performed at a rail head surface temperature of no higher than 900°C and no lower than the Ar_3 transformation point or the Ar_{cm} transformation point, a head cumulative area reduction rate of 20% or greater, and with a reaction force ratio of 1.25 or greater, which is a value obtained by dividing a reaction force value of the roller by a reaction force value for the same cumulative area reduction rate and a rolling temperature of 950°C. After the finish rolling, the rail head surface is cooled to 550°C or lower at a cooling rate of 2°C/s to 30°C/s by accelerated cooling or natural cooling.

[0007] Rails used in high axle load railways, the main examples of which being railways for freight transportation and mining, are expected to have superior wear resistance in order to improve rail durability and, in response, there have been various proposals for rails, such as described above, that focus on increasing hardness.

CITATION LIST

Patent Literature

[0008] PTL 1: JP 4272385 B
PTL 2: JP 3078461 B
PTL 3: JP 3081116 B
PTL 4: JP 3513427 B
PTL 5: JP 4390004 B
PTL 6: JP 2009-108396 A
PTL 7: JP 2009-235515 A
PTL 8: JP 3423811 B
PTL 9: JP 3113137 B
PTL 10: JP 2008-50687 A

SUMMARY

(Technical Problem)

[0009] A rail is manufactured by hot rolling a steel raw material to a length of as long as 100 m or greater and, hardness of the rail exhibits variation in the rail length direction that is dependent on the method of manufacture. Consequently, the rail may experience uneven wear when laid and thus may be unable to sufficiently demonstrate its effects. Although it is extremely important, therefore, to reduce hardness variation in the longitudinal direction of rolling, PTL 1-10 make no mention of this hardness variation.

[0010] In consideration of the above, an objective of the present disclosure is to provide a rail that exhibits excellent wear resistance and reduced hardness variation in the rail length direction, and also a method for manufacturing the rail.

(Solution to Problem)

[0011] The inventors sampled test pieces from steel materials having pearlite structures corresponding to rails of differing hardness and conducted a rail wear test with respect to the test pieces in order to investigate a relationship between hardness and wear. The results of the investigation are shown in FIG. 1.

The wear test was a comparative test in which actual contact conditions between a pearlite steel rail and a wheel were simulated using a Nishihara type wear test apparatus that enables wear resistance evaluation in a short period of time. The test was conducted as illustrated in FIG. 2 by rotating a Nishihara type wear test piece 1 of 30 mm in outer diameter, sampled from a rail head, in contact with a tire test piece 2. The arrows in FIG. 2 indicate the rotation directions of the Nishihara type wear test piece 1 and the tire test piece 2, respectively. The tire test piece was obtained by sampling a round bar of 32 mm in diameter from a normal rail head stipulated by JIS E1101, subjecting the round bar to heat treatment such as to have a tempered martensite structure and a Brinell hardness (Brinell load 29.4 kN) of HB 370, and subsequently processing the round bar into the shape illustrated in FIG. 2. Nishihara type wear test pieces 1 were sampled from two locations in a rail head 3 as illustrated in FIG. 3. A test piece sampled from a surface layer of the rail head 3 is denoted Nishihara type wear test piece 1a and a test piece sampled from an inner part of the rail head 3 is denoted Nishihara type wear test piece 1b. The center, in a longitudinal direction, of the Nishihara type wear test piece 1b sampled from the inner part of the rail head 3 is located at a depth of from 24 mm to 26 mm (average value 25 mm) from an upper surface of the rail head 3. The test was conducted in dry ambient conditions and the wear was measured after 1.8×10^5 rotations under conditions of a contact pressure of 1.2 GPa, a slip ratio of −10%, and a rotational speed of 750 rpm (tire test piece: 750 rpm). The wear was calculated from the difference in the mass of the test piece measured before and after the test.

[0012] As illustrated in FIG. 1, wear resistance increases with increasing hardness. For example, wear resistance of a rail having a hardness of HB 400 or higher can be improved by 15% compared to an ordinary heat treated rail (HB 370). However, if the hardness exhibits a large amount of variation in the rail length direction, a difference in wear behavior arises for hard portions and soft portions. For example, in a situation in which the hardness is HB 415 points and exhibits variation of ±15 or less (i.e., the hardness varies within a range from at least HB 400 to no greater than HB 430), the wear changes from 0.37 g to 0.3 g and accordingly exhibits variation of 20% or less. On the other hand, in a situation in which the hardness is HB 415 points and exhibits variation of ±30 (i.e., the hardness varies in a range from at least HB 385 to no greater than HB 445), the wear changes from

0.40 g to 0.27 g and accordingly exhibits variation of 33%. In consideration of the above, reducing hardness variation in the longitudinal direction of a rail in accompaniment to increasing rail hardness enables uniform rail wear and contributes to improving rail life. It is preferable for wear to be as uniform as possible in the length direction because wear proceeds due to contact between the rail and wheels during use. Taking into account the results of the test described above, hardness variation in the rail length direction is preferably of a level such that wear variation is 20% or less. The inventors discovered that surface hardness variation of ±HB 15 or less ensures superior wear resistance along the length direction and contributes to improved rail life. This discovery led to the present disclosure.

[0013] Specifically, primary features of the present disclosure are as follows.

(1) A rail comprising

a chemical composition containing (consisting of), in mass%:

0.60% to 1.0% of C;

0.1% to 1.5% of Si;

0.01% to 1.5% of Mn;

0.035% or less of P;

0.030% or less of S; and

0.1% to 2.0% of Cr,

the balance being Fe and incidental impurities, wherein

surface hardness of a head of the rail exhibits variation of ±HB 15 points or less in a length direction of the rail.

Herein, the surface hardness variation in the rail length direction refers to the difference between an average value of Brinell hardness of the top of the rail head calculated from measurements made at intervals of 5 m in a rolling length direction along the entire length of the rail (for example, 25 m to 100 m) and the value of Brinell hardness measured at each of the measurement points. In other words, surface hardness variation of ±HB 15 points or less in the rail length direction signifies that when an average value for Brinell hardness is calculated from all hardness values measured at 5 m intervals (i.e., values measured at 6 points in the case of a total length of 25 m, 11 points in the case of a total length of 50 m, and 21 points in the case of a total length of 100 m), the maximum difference in Brinell hardness between the average value and the values for the measurement points is ±15 points or less. Note that Brinell hardness is measured after removing 0.5 mm or greater of a decarburized layer using a grinder or the like.

[0014] (2) The rail described in (1), wherein

the chemical composition further contains, in mass%, one or more of:

1.0% or less of Cu;
0.5% or less of Ni;
0.5% or less of Mo; and
0.15% or less of V.

[0015] (3) The rail described in (1) or (2), wherein the surface hardness of the head of the rail is HB 400 or greater.

[0016] (4) The rail described in any one of (1) to (3), wherein the variation of the surface hardness is ±HB 10 points or less.

[0017] (5) A rail manufacturing method comprising:

heating to 1200°C or higher, a steel raw material having a chemical composition containing (consisting of), in mass%,

0.60% to 1.0% of C,
0.1% to 1.5% of Si,
0.01% to 1.5% of Mn,
0.035% or less of P,
0.030% or less of S, and
0.1% to 2.0% of Cr,
the balance being Fe and incidental impurities;

hot rolling the steel raw material after the heating, the hot rolling being performed such that rolling in a rail length direction in a temperature region not exceeding 1000°C is performed over a plurality of passes with a time interval between passes exhibiting variation of 15 s or less in the rail length direction, a cumulative area reduction rate of 40% or greater for a portion forming a rail head, and a finisher delivery temperature of 900°C or higher; and

cooling the rail head after the hot rolling from a cooling start temperature of 800°C or higher to a cooling stop temperature of 600°C or lower at a cooling rate of 1°C/s to 10°C/s.

[0018] (6) The rail manufacturing method described in (5), wherein

the chemical composition further contains, in mass%, one or more of:

1.0% or less of Cu;
0.5% or less of Ni;
0.5% or less of Mo; and
0.15% or less of V.

[0019] (7) The rail manufacturing method described in (5) or (6), wherein the cooling rate in the cooling exhibits variation of ±1°C/s or less in the rail length direction.

(Advantageous Effect)

[0020] The present disclosure enables minimization of hardness variation in a rail length direction and effectively improves rail durability (extends rail life), particularly in the case of a rail that is laid in a high axle load environment such as a heavy freight railway or a mining railway, and thus demonstrates a significant effect in industrial use.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] In the accompanying drawings:

FIG. 1 is a graph illustrating a relationship between the rail material hardness and wear;

FIG. 2 illustrates a Nishihara type wear test piece of which wear resistance is evaluated, wherein (a) is a plan view and (b) is a side view; and

FIG. 3 is a cross-sectional view of a rail head illustrating sampling positions of Nishihara type wear test pieces.

DETAILED DESCRIPTION

[0022] Firstly, the reasons for limitations on each component in the chemical composition of a rail will be explained. When components are expressed in "%", this refers to "mass%" unless otherwise specified.

C: 0.60% to 1.0%

C is an important element in a pearlitic rail for forming cementite, increasing hardness and strength, and improving wear resistance. However, these effects are small when C content is less than 0.60% and therefore the lower limit for the C content is 0.60%. On the other hand, although an increase in the C content, and thus an increase in cementite content, is expected to lead to higher hardness and strength, an increase in the C content also decreases ductility. Furthermore, an increase in the C content broadens the $\gamma + \theta$ temperature range and promotes softening of a heat-affected zone. Taking into account these influences, the upper limit for the C content is 1.0%. The C content is preferably in a range of 0.73% to 0.85%.

[0023] Si: 0.1% to 1.5%

Si is added to the rail material as a deoxidizing material and in order to raise the equilibrium transformation temperature (TE) and reinforce the pearlite structure (increase hardness by refining the lamellar structure). However, these effects are small when Si content is less than 0.1%. On the other hand, an increase in the Si content promotes decarburization and promotes formation of rail surface defects. Therefore, the upper limit for the Si content is 1.5%. The Si content is preferably in a range of 0.5% to 1.3%.

[0024] Mn: 0.01% to 1.5%

Mn has an effect of lowering the actual pearlite transformation temperature and narrowing pearlite lamellar spacing, and is an effective element for achieving high hardness. However, these effects are small when Mn content is less than 0.01%. On the other hand, addition of greater than 1.5% of Mn to improve hardenability facilitates transformation to bainite or martensite. Therefore, the upper limit for the Mn content is 1.5%. The Mn content is preferably in a range of 0.3% to 1.2%.

[0025] P: 0.035% or less

P content of greater than 0.035% decreases toughness and ductility. Therefore, the upper limit for the P content is 0.035%. A preferable range for the P content has an upper limit of 0.025%. On the other hand, taking into consideration the increased cost of steelmaking when special refining or the like is performed, the lower limit for the P content is preferably

0.001%.

[0026] S: 0.030% or less

S forms coarse MnS extending in the rolling direction and decreases ductility and toughness. Therefore, the upper limit for S content is 0.030%. On the other hand, restricting the S content to less than 0.0005% requires a significant increase in steel making cost due to, for example, a large increase in steelmaking process time. Therefore, the lower limit for the S content is preferably 0.0005%. The S content is preferably 0.001% to 0.015%.

[0027] Cr: 0.1% to 2.0%

Cr raises the equilibrium transformation temperature (TE), contributes to refinement of pearlite lamellar spacing, and increases hardness and strength. In order to obtain such effects, it is necessary to add 0.2% or greater of Cr. On the other hand, adding greater than 2.0% of Cr increases occurrence of welding defects while also increasing hardenability and promoting martensite formation. Therefore, the upper limit for Cr content is 2.0%. The Cr content is more preferably in a range of 0.26% to 1.00%.

[0028] Besides the chemical components described above, one or more of 1.0% or less of Cu, 0.5% or less of Ni, 0.5% or less of Mo, and 0.15% or less of V may be added.

Cu: 1.0% or less

Cu is an element that can provide even higher hardness through solid solution strengthening. Cu also has an effect of suppressing decarburization. In order to obtain these effects, 0.01% or greater of Cu is preferably added. On the other hand, adding greater than 1.0% of Cu makes surface cracking more likely to occur during continuous casting or rolling. Therefore, the upper limit for Cu content is preferably 1.0%. Moreover, the Cu content is more preferably in a range of 0.05% to 0.6%.

[0029] Ni: 0.5% or less

Ni is an effective element for improving toughness and ductility. Ni is also an effective element for inhibiting Cu cracking through combined addition with Cu. Therefore, in a situation in which Cu is added, Ni is preferably also added. However, these effects are not noticeable when Ni content is less than 0.01%. Therefore, in a situation in which Ni is added, the lower limit for the Ni content is preferably 0.01% or greater. On the other hand, adding greater than 0.5% of Ni increases hardenability and promotes formation of martensite. Therefore, the upper limit for the Ni content is preferably 0.5%. The Ni content is more preferably in a range of 0.05% to 0.50%.

[0030] Mo: 0.5% or less

Mo is an effective element for increasing strength, but this effect is small when Mo content is less than 0.01%. Therefore, the lower limit for the Mo content is preferably 0.01%. On the other hand, adding greater than 0.5% of Mo causes formation of martensite as a result of increased hardenability and dramatically decreases toughness and ductility. Therefore, the upper limit for the Mo content is preferably 0.5%. The Mo content is more preferably in a range of 0.05% to 0.30%.

[0031] V: 0.15% or less

V forms VC, VN, or the like as a fine precipitate in ferrite and is an element that contributes to achieving high hardness through precipitation strengthening of ferrite. The solvation temperature of VC or VN is sufficiently lower than that of Ti or Nb such as to have little influence on recrystallization behavior of austenite during rolling and therefore has little influence on variation of properties in the rail length direction. Moreover, V also acts as a hydrogen trapping site and can be expected to exhibit an effect of inhibiting delayed fracture. Therefore, 0.001% or greater of V is preferably added. On the other hand, when greater than 0.15% of V is added, the above-described effects reach saturation and the alloying cost increases dramatically. Therefore, the upper limit for V content is preferably 0.15%. The V content is more preferably in a range of 0.005% to 0.12%.

[0032] The balance excluding the aforementioned components is Fe and incidental impurities.

For example, up to 0.006% of N and 0.003% of O may be allowed as incidental impurities. Furthermore, although Al is effective as a deoxidizing material, Al forms cluster-shaped AlN, which significantly decreases rolling fatigue characteristics. Therefore, Al content is preferably 0.003% or less. Nb and Ti are also contained as incidental impurities as described below.

[0033] Nb: 0.003% or less

Ti: 0.003% or less

Nb and Ti are effective elements for improving hardness and wear resistance due to forming carbides or carbonitrides that strengthen the matrix. However, Nb and Ti are harmful elements that promote hardness variation of the rail in the longitudinal direction and are therefore not generally added, although incidentally mixed in Nb and Ti of 0.003% or less is allowable. Specifically, addition of Nb or Ti causes hardness to change to a greater extent in accordance with material heating, rolling, or cooling conditions and thus causes changes in hardness in the rolling length direction to be more sensitively associated with variation in these conditions. In metallurgical terms, inhomogeneity of heated austenite particles is promoted and, at the same time, inhibition of recrystallization of austenite during rolling and a change in pearlite transformation temperature associated therewith are greatly increased compared to steel in which Nb and Ti are not added, and this may promote hardness variation.

[0034] In addition to the chemical composition described above, it is essential that surface hardness exhibits variation of ±HB 15 points or less in the rail length direction. The reason for this is that the change in rail wear reaches 20% or greater if the hardness variation is greater than ±HB 15 points. Furthermore, it is more preferable that the surface hardness exhibits variation of ±HB 10 points or less in the rail length direction because hardness variation of ±HB 10 points or less enables restriction of the change in rail wear to less than 15%.

[0035] The following provides a specific description of rail manufacture conditions.

First, the steel raw material that is used is preferably continuous-cast steel obtained through continuous casting of molten steel that has been adjusted to the chemical composition described above through steelmaking processes such as a process in a blast furnace, molten iron pretreatment, a process in a converter, and RH degassing.

[0036] The steel raw material is hot rolled to form a rail shape by ordinary caliber rolling or universal rolling. The following explains the reasons for limitations placed on conditions during the heating and rolling described above and also conditions during subsequent cooling.

[0037] [Heating temperature prior to hot rolling: 1200°C or higher]

Heating of the produced steel raw material is required to 1200°C or higher. This is performed with the main objective of sufficiently reducing deformation resistance so as to enable use of a lighter rolling load and also with the objective of homogenization. In order to sufficiently obtain these effects, the heating temperature is required to be 1200°C or higher. Although it is not necessary to set a specific upper limit, the heating temperature is preferably 1300°C or lower from a viewpoint of suppressing scale loss and decarburization.

[0038] [Rolling in a rail length direction in a temperature region not exceeding 1000°C is performed over a plurality of passes with a time interval between passes exhibiting variation of 15 s or less in the rail length direction]

The steel raw material heated as described above is shaped into a rail shape by hot rolling. In the hot rolling, it is important that a plurality of rolling passes at temperatures not exceeding 1000°C are performed by rolling repeatedly in a single direction in order to minimize variation in a time interval between passes. Note that the time interval between passes refers to the interval between a time when a given portion in the longitudinal direction (rolling direction) of a rolled rail material is bitten by a roller and a time when the given portion is next bitten by the roller. The time interval between passes differs the most for the top (leading end) of the rolled rail material and the bottom (trailing end) of the rolled rail material.

[0039] In conventional reverse rolling, during an interval between a rolled top portion (leading end) being bitten by the roller in a given pass and starting to be bitten in a next pass, the next pass is performed in order by first feeding a rolled bottom portion (trailing end) to the roller, which lengthens the time interval between passes for the rolled top portion. On the other hand, after the rolled bottom portion (trailing end) has passed through in a given pass, the bottom portion is bitten first by the roller in the next pass, which shortens the time interval between passes. The difference in the time interval between passes for the leading end and the trailing end described above, which is a characteristic of reverse rolling, influences the state of the austenite structure and also influences hardness variation after transformation to pearlite. In contrast, when continuous rolling is performed in a single direction, the difference in the time interval between passes for a leading end and a trailing end of a rolled material is fundamentally small. Therefore, inhomogeneity of the austenite structure arising from the above-described difference in the time interval between passes can be resolved. It is therefore necessary for the aforementioned difference in the time interval between passes to be 15 s or less. In other words, a difference in the time interval between passes of 15 s or less can suppress hardness variation in the rail length direction. The difference in the time interval between passes is preferably 12 s or less.

[0040] The above stipulations are conditions to be applied to rolling performed at 1000°C or lower in the hot rolling. Reverse rolling may be used for rolling performed in a temperature region exceeding 1000°C, a representative example of which is rough rolling. In other words, so long as rolling at 1000°C or lower is performed continuously in a single direction, a preceding stage of rolling in a temperature region exceeding 1000°C may be performed freely. In the hot rolling, two to seven passes of rolling are preferably performed at 1000°C or lower. The reason for this is that single pass rolling requires a large rolling load and makes shaping difficult, whereas more than seven passes tends to cause a fairly inhomogeneous austenite state and increase hardness variation.

[0041] [Cumulative area reduction rate of 40% or greater for a portion forming a rail head]

The cumulative area reduction rate of rolling performed at 1000°C or lower is required to be 40% or greater. The reason for this is that it is necessary to perform 40% or greater of area reduction processing at 1000°C or lower in order to promote recrystallization refinement of austenite. If the area reduction rate for rolling at 1000°C or lower is less than 40%, recrystallization refinement of austenite is insufficient and coarse austenite may partially remain, which results in increased hardness variation in the rail length direction (rolling direction).

[0042] [Finisher delivery temperature of 900°C or higher]

When performing continuous rolling in a single direction in order to reduce variation in the time interval between passes along the whole length of the rolled material, a finisher delivery temperature of 900°C or higher is preferable. The reason for this it that if the finisher delivery temperature is lower than 900°C, overall hardness decreases and variation thereof increases due to reasons such as a decrease in the cooling start temperature of on-line heat treatment performed consecutively after rolling and promotion of transformation to pearlite (transformation at higher temperature). Therefore, the finisher delivery temperature is preferably 900°C or higher in order to prevent a decrease in hardness such as described above.

[0043] Cooling is performed consecutively after the hot rolling under the following conditions.

[Cooling of the rail head from a cooling start temperature of 800°C or higher to a cooling stop temperature of 600°C or lower at a cooling rate of 1°C/s to 10°C/s]

Firstly, the cooling start temperature is preferably 800°C or higher. Specifically, a cooling start temperature of lower than 800°C may not enable sufficient supercooling or allow sufficient surface hardness to be obtained. The cooling stop temperature is required to be 600°C or lower. Sufficient hardness cannot be obtained if the cooling stop temperature is greater than 600°C. Although no specific lower limit is given, saturation is reached in terms of hardness once cooling is performed to 400°C or lower and productivity is adversely affected by increased cooling time. Therefore, cooling is preferably stopped at 400°C or higher.

The cooling rate is in a range of 1°C/s to 10°C/s. A cooling rate of greater than 10°C/s does not allow sufficient time for pearlite transformation, causes formation of bainite and martensite, and thus reduces toughness, ductility, and fatigue resistance. On the other hand, a cooling rate of less than 1°C/s does not allow sufficient hardness to be obtained. The cooling rate is preferably in a range of 2°C/s to 8°C/s.

Moreover, the cooling rate preferably exhibits variation of ±1°C/s or less in the rolling longitudinal direction. Restricting cooling rate variation to ±1°C/s or less reduces variation in pearlite lamellar spacing, enables hardness variation of ±HB 10 or less to be achieved, and reduces wear resistance variation and fatigue resistance variation in the rail longitudinal direction.

The cooling performed consecutively after the hot rolling is preferably performed by air blast cooling or mist cooling. Air blast cooling is accelerated cooling in which air is forcefully blown against the rail head. Mist cooling involves mixing air and water and blowing a water mist against the rail head.

[0044] In order to control and minimize cooling rate variation in the rolling longitudinal direction, in the case of air blast cooling, for example, it is necessary to control air pressure at intervals of 5 m or less (preferably 3 m or less), adjust air pressure on-line in accordance with temperature variation of the rail in the longitudinal direction measured before the cooling, and perform control such that the cooling rate is constant in the length direction. In the case of mist cooling, cooling is preferably performed by controlling the amount of water and pressure in the longitudinal direction in the same way as described above.

[0045] Through the above-described chemical composition and performance of the above-described rolling and cooling, a pearlitic steel rail can be obtained that has a surface hardness of preferably HB 400 or greater and that exhibits surface hardness variation of ±HB 15 points or less in the rail length direction. In other words, a homogeneous and high-hardness pearlitic steel rail that exhibits little hardness variation in the rolling length direction can be obtained.

EXAMPLES

[0046] Steels having the chemical compositions shown in Table 1 were made and cast steels obtained through continuous casting thereof were subjected to heating, hot rolling, and cooling to manufacture a 136-pound rail or a 141-pound rail for each steel. The manufacture conditions are shown together with investigation results for surface hardness and variation thereof in Table 2.

[0047] [Table 1]

Table 1

Steel symbol	C	Si	Mn	P	S	Cr	Cu	Ni	Mo	V	Nb*	Ti*	sol Al*	N*	O*	Remarks
A	0.82	0.53	0.56	0.016	0.004	0.76	-	-	-	-	0.001	0.001	0.002	0.0041	0.0015	Example
B	0.80	1.28	0.23	0.018	0.003	0.38	-	-	-	0.053	0.001	0.001	0.002	0.0029	0.0018	Example
C	0.89	0.26	1.43	0.012	0.005	0.26	-	-	0.12	-	0.002	0.001	0.001	0.0040	0.0018	Example
D	0.76	1.43	0.93	0.015	0.007	0.53	0.31	0.15	-	0.072	0.001	0.002	0.001	0.0045	0.0013	Example
E	0.98	0.63	0.78	0.018	0.005	0.22	-	-	-	-	0.001	0.001	0.001	0.0042	0.0012	Example
F	0.82	0.95	0.48	0.013	0.004	1.43	-	-	-	0.036	0.001	0.001	0.002	0.0055	0.0016	Example
G	0.56	0.53	1.32	0.016	0.005	0.53	-	-	-	-	0.002	0.001	0.002	0.0035	0.0015	Comparative example
H	0.79	1.58	0.13	0.02	0.007	0.23	-	-	-	-	0.001	0.002	0.001	0.0051	0.0015	Comparative example
I	0.81	0.05	1.59	0.016	0.005	0.23	-	-	-	-	0.001	0.001	0.002	0.0040	0.0012	Comparative example
J	0.68	0.43	1.62	0.021	0.008	0.18	-	-	-	-	0.001	0.001	0.002	0.0033	0.0012	Comparative example
K	0.81	0.55	0.48	0.018	0.005	0.08	-	-	-	-	0.001	0.002	0.001	0.0043	0.0015	Comparative example
L	0.82	0.43	0.22	0.015	0.003	2.03	-	-	-	-	0.001	0.001	0.003	0.0060	0.0018	Comparative example
M	1.07	0.38	0.73	0.018	0.005	0.33	-	-	-	-	0.001	0.001	0.002	0.0038	0.0016	Comparative example
N	0.82	1.24	0.10	0.013	0.004	1.36	-	-	-	-	0.001	0.002	0.002	0.0045	0.0015	Example

*Contents of Nb, Ti, sol Al, N, and O are as incidental impurities

[0048] Herein, the variation in the time interval between passes in the rolling conditions indicates the difference between the time elapsing from a leading end of a rolled material being rolled to the leading end being next rolled and the time elapsing from a trailing end of the rolled material being rolled to the trailing end being next rolled. As explained further above, when rolling is performed by conventional reverse rolling, the time interval between passes is extended for a rolled top portion and shortened for a rolled bottom portion. Thus, the difference in the time interval between passes for the leading end (top portion) and the trailing end (bottom portion) of the rolled material is particularly evident in reverse rolling. In contrast, the difference in the time interval between passes associated with a leading end and a trailing end of a rolled material is smaller in continuous rolling in a single direction and therefore inhomogeneity of a produced structure can be resolved as shown in Table 2.

[0049] Note that the cooling start temperature and the cooling stop temperature are results for surface temperature of a rail corner measured by a thermoviewer. The rail cooling rate is an average value of cooling rates measured from cooling start and end temperatures and cooling times measured at 5 m intervals in the length direction. With regards to cooling rate variation in the length direction, it was determined whether the difference between a largest value and a smallest value in variation of the cooling rates was greater than ±1°C/s or was less than or equal to ±1°C/s.

Furthermore, the rail head surface hardness and microstructure of each of the manufactured rails was evaluated. The rail head surface hardness was evaluated by removing 0.5 mm or greater of a decarburized layer using a grinder and measuring the Brinell hardness of points at 5 m intervals in the rail length direction. In the same way, microscope samples were cut out and the microstructures thereof were observed.

The evaluation results are shown in Table 2.

[0050] [Table 2]

Table 2

No.	Steel symbol	Heating		Rolling conditions			Cooling conditions						Brinell hardness of surface		Remarks
		Temperature (°C)	Use of continuous rolling at 1000°C or lower	Variation in time interval between passes (s)	Area reduction rate at 1000°C or lower (%)	Finisher delivery temperature (°C)	Cooling method	Length direction cooling control	Start temperature (°C)	Stop temperature (°C)	Cooling rate (°C/s)	Cooling rate variation (°C/s)	Average surface hardness (HB)	Surface hardness variation (HB)	
1	A	1240	Reverse rolling	25	45	950	Air blast	No	760	430	3.4	>1	422	23	Conventional example
2	A	1230	Reverse rolling	22	45	970	Air blast	No	780	470	3.5	>1	426	18	Comparative example
3	A	1220	Single-direction continuous	12	45	950	Air blast	No	820	450	3.3	>1	420	13	Example
4	A	1180	Single-direction continuous	12	45	920	Air blast	No	770	450	2.8	>1	398	17	Comparative example
5	A	1220	Single-direction continuous	10	45	930	Air blast	Yes	820	450	3.4	≤1	420	8	Example
6	A	1240	Single-direction continuous	12	45	940	Mist	No	820	430	6.7	>1	439	14	Example
7	A	1230	Single-direction continuous	8	45	900	Air blast	Yes	800	430	3.3	≤1	416	7	Example
8	A	1220	Single-direction continuous	12	37	950	Air blast	No	810	450	3.5	>1	422	18	Comparative example
9	A	1240	Single-direction continuous	10	45	880	Air blast	No	830	450	3.4	>1	403	17	Comparative example
10	A	1230	Single-direction continuous	17	45	910	Air blast	No	810	460	3.4	>1	400	17	Comparative example
11	A	1250	Single-direction continuous	12	45	920	Air blast	Yes	820	430	3.5	≤1	435	7	Example
12	A	1230	Single-direction continuous	12	45	920	Mist	Yes	830	400	7.0	≤1	455	9	Example
13	A	1250	Single-direction continuous	12	45	910	Air blast	Yes	820	620	3.7	≤1	373	7	Comparative example
14	A	1250	Single-direction continuous	12	45	910	Air blast	Yes	810	430	0.5	≤1	351	7	Comparative example
15	A	1250	Single-direction continuous	12	45	920	Mist	Yes	820	400	12	≤1	789	82	Comparative example Martensite formation

Length direction cooling control: No → Variation > 1°C/s
Length direction cooling control: Yes → Variation ≤ 1°C/s

Table 2 (cont'd)

No.	Steel symbol	Heating		Rolling conditions			Cooling conditions						Brinell hardness of surface		Remarks
		Temperature (°C)	Use of continuous rolling at 1000°C or lower	Variation in time interval between passes (s)	Area reduction rate at 1000°C or lower (%)	Finisher delivery temperature (°C)	Cooling method	Length direction cooling control	Start temperature (°C)	Stop temperature (°C)	Cooling rate (°C/s)	Cooling rate variation (°C/s)	Average surface hardness (HB)	Surface hardness variation (HB)	
16	B	1220	Single-direction continuous	13	45	950	Air blast	No	850	450	3.7	>1	441	12	Example
17	B	1250	Single-direction continuous	20	40	970	Air blast	Yes	840	420	4.0	≤1	436	7	Example
18	B	1230	Single-direction continuous	12	45	950	Air blast	Yes	820	460	3.8	≤1	455	8	Example
19	C	1200	Single-direction continuous	18	45	950	Air blast	No	830	450	3.5	>1	415	12	Example
20	C	1230	Single-direction continuous	18	40	930	Air blast	Yes	820	470	3.8	≤1	430	8	Example
21	D	1220	Single-direction continuous	15	45	950	Air blast	No	810	470	3.5	>1	430	11	Example
22	E	1240	Single-direction continuous	13	45	930	Air blast	No	810	450	3.3	>1	420	12	Example
23	E	1240	Single-direction continuous	10	37	940	Air blast	Yes	820	440	3.4	≤1	432	7	Example
24	F	1250	Single-direction continuous	15	45	920	Air blast	No	830	480	4.2	≤1	458	8	Example
25	G	1230	Single-direction continuous	18	45	920	Air blast	No	820	460	3.6	≤1	367	10	Comparative example
26	H	1240	Single-direction continuous	10	45	910	Air blast	Yes	800	450	3.5	≤1	486	35	Comparative example Martensite formation
27	I	1230	Single-direction continuous	12	45	930	Air blast	Yes	820	470	2.6	≤1	382	7	Comparative example
28	J	1250	Single-direction continuous	12	45	930	Mist	Yes	830	460	8.2	≤1	483	36	Comparative example Martensite formation
29	K	1250	Single-direction continuous	15	45	920	Air blast	Yes	800	450	4.2	≤1	362	9	Comparative example
30	L	1220	Single-direction continuous	12	45	930	Air blast	Yes	810	430	4.3	≤1	503	20	Comparative example Martensite formation
31	M	1230	Single-direction continuous	12	45	920	Air blast	Yes	820	430	3.5	≤1	433	8	Comparative example Low ductility
32	N	1250	Single-direction continuous	12	45	930	Air blast	Yes	820	410	4.2	≤1	421	7	Example

Length direction cooling control: No → Variation > 1°C/s
Length direction cooling control: Yes → Variation ≤ 1°C/s

[0051] The hardness of rails according to the present disclosure exhibited extremely small variation of ±HB 15 or less in the rail length direction, whereas the hardness of rails that deviated from the scope of the present disclosure in terms of either or both of chemical composition and rolling conditions exhibited variation of greater than ±HB 15.

CLAIMS

1. A rail comprising

a chemical composition containing, in mass%:

0.60% to 1.0% of C;

0.1% to 1.5% of Si;

0.01% to 1.5% of Mn;

0.035% or less of P;

0.030% or less of S; and

0.1% to 2.0% of Cr,

the balance being Fe and incidental impurities, wherein

surface hardness of a head of the rail exhibits variation of ±HB 15 points or less in a length direction of the rail.

2. The rail of claim 1, wherein

the chemical composition further contains, in mass%, one or more of:

1.0% or less of Cu;

0.5% or less of Ni;

0.5% or less of Mo; and

0.15% or less of V.

3. The rail of claim 1 or 2, wherein

the surface hardness of the head of the rail is HB 400 or greater.

4. The rail of any one of claims 1-3, wherein

the variation of the surface hardness is ±HB 10 points or less.

5. A rail manufacturing method comprising:

heating to 1200°C or higher, a steel raw material having a chemical composition containing, in mass%:

0.60% to 1.0% of C,

0.1% to 1.5% of Si,

0.01% to 1.5% of Mn,

0.035% or less of P,
0.030% or less of S, and
0.1% to 2.0% of Cr,
the balance being Fe and incidental impurities;

hot rolling the steel raw material after the heating, the hot rolling being performed such that rolling in a rail length direction in a temperature region not exceeding 1000°C is performed over a plurality of passes with a time interval between passes exhibiting variation of 15 s or less in the rail length direction, a cumulative area reduction rate of 40% or greater for a portion forming a rail head, and a finisher delivery temperature of 900°C or higher; and

cooling the rail head after the hot rolling from a cooling start temperature of 800°C or higher to a cooling stop temperature of 600°C or lower at a cooling rate of 1°C/s to 10°C/s.

6. The rail manufacturing method of claim 5, wherein

the chemical composition further contains, in mass%, one or more of:

1.0% or less of Cu;
0.5% or less of Ni;
0.5% or less of Mo; and
0.15% or less of V.

7. The rail manufacturing method of claim 5 or 6, wherein

the cooling rate in the cooling exhibits variation of ±1°C/s or less in the rail length direction.

FIG. 1

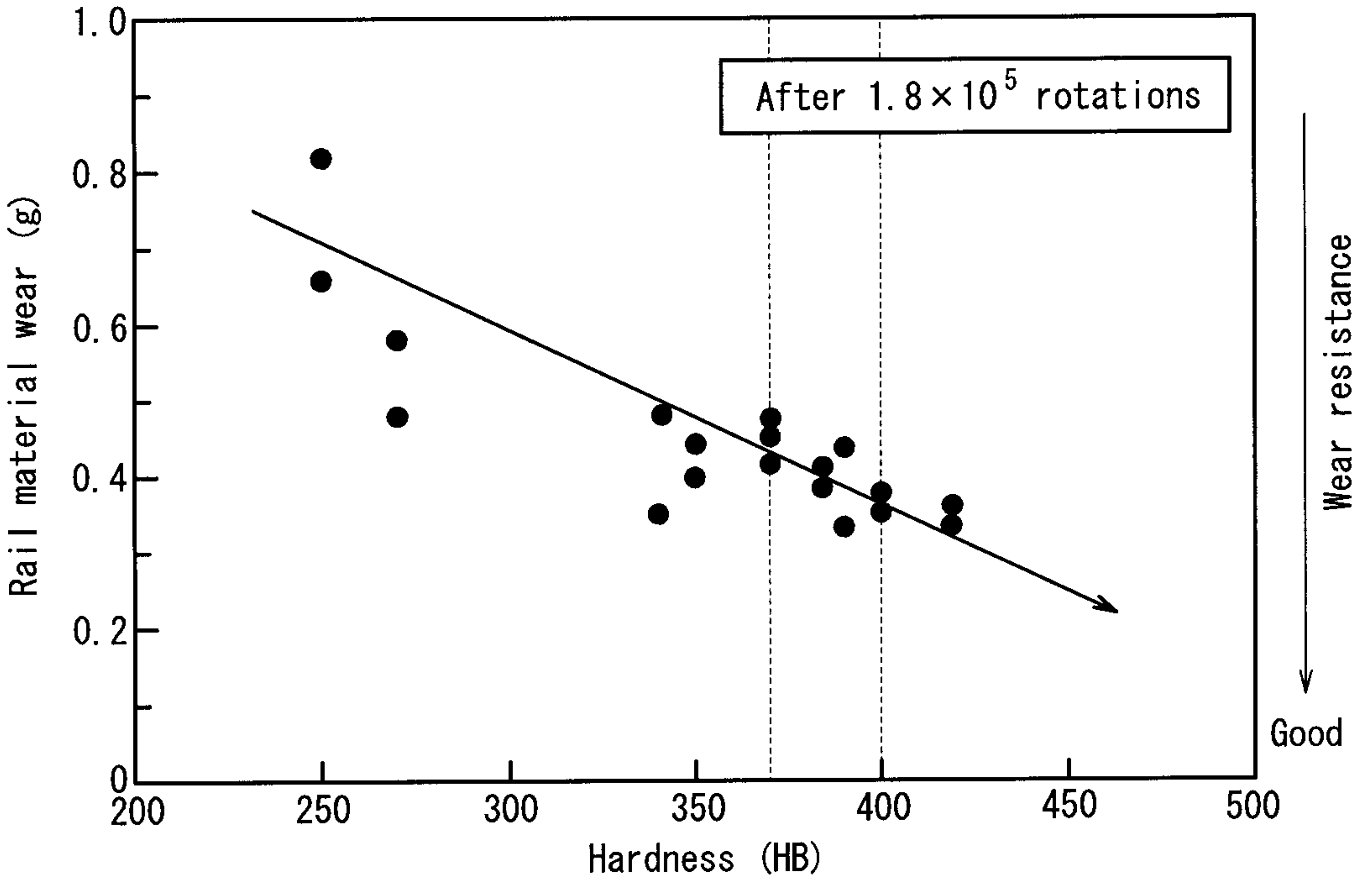
After 1.8×10^5 rotations
Rail material wear (g)
1.0
0.8
0.6
0.4
0.2
0
200
250
300
350
400
450
500
Hardness (HB)
Wear resistance
Good

FIG. 2

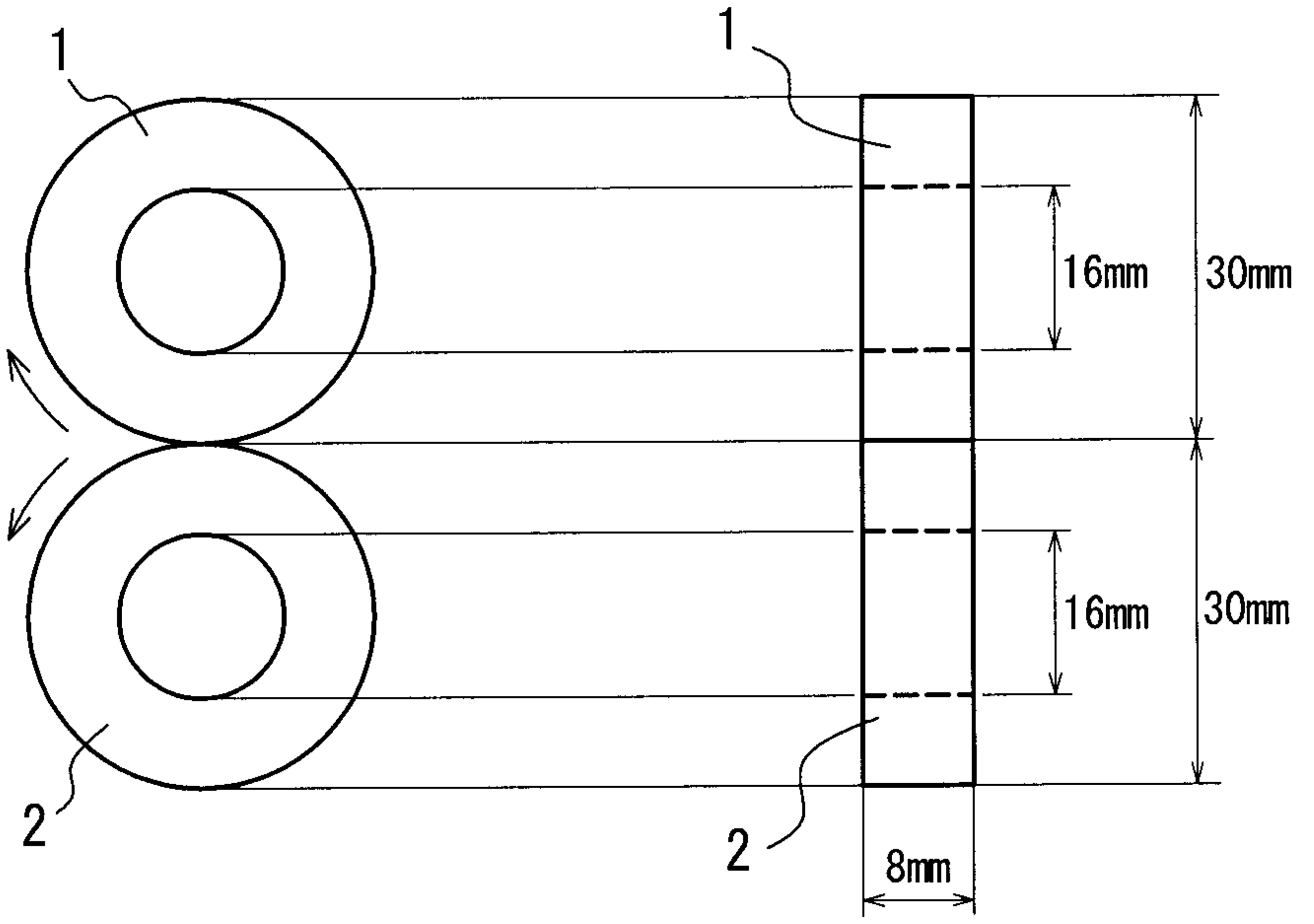

FIG. 3