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(54) **RAIL MANUFACTURING METHOD AND RAIL MANUFACTURING APPARATUS**

VERFAHREN ZUR HERSTELLUNG VON SCHIENEN UND VORRICHTUNG ZUR SCHIENENHERSTELLUNG

PROCÉDÉ DE FABRICATION DE RAIL ET APPAREIL DE FABRICATION DE RAIL

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Description

Technical Field

[0001] The present invention relates to a method for manufacturing a pearlitic steel rail with excellent ductility obtained by performing rough rolling, finish rolling, and heat treatment of a heated bloom and particularly relates to a method and an apparatus for manufacturing a rail having ductility improved by refining the pearlite block or colony size.

Background Art

[0002] A rail in which the structure of a head portion forms a pearlite structure is generally manufactured by the following manufacturing method.

[0003] First, a bloom cast by a continuous casting method is heated to 1100°C or more, and then hot-rolled into a predetermined rail shape by rough rolling and finish rolling. A rolling method in each rolling process is performed combining caliber rolling and universal rolling. Herein, the rolling is performed in a plurality of passes in the rough rolling or in a plurality of passes or a single pass in the finish rolling.

[0004] Then, crops at end portions of the hot-rolled rail are sawn. The length of the hot-rolled rail is 50 to 200 m. Therefore, when a heat treatment apparatus has a length limitation, the rail is sawn into a predetermined length, e.g., 25 m, simultaneously with the sawing of the crops.

[0005] Furthermore, when the rail is required to have wear resistance, the rail is subjected to heat treatment by the heat treatment apparatus (heat treatment process) subsequent to the hot-rolling process. Herein, the wear resistance improves when the heat treatment start temperature is higher. Therefore, a re-heating process of heating the rail may be provided before the heat treatment process. In the heat treatment process, the rail is fixed with a restraining device, such as a clamp, and then a head portion, a foot portion, and, as necessary, an web portion are forcibly cooled using a cooling medium, such as air, water, and mist. In the heat treatment process, the forcible cooling is usually performed until the temperature of the head portion reaches 650°C or less.

[0006] Thereafter, the restraint of the rail by the clamp is released, and then the rail is conveyed to a cooling bed. On the cooling bed, the rail is cooled until the temperature reaches 100°C or less.

[0007] For example, a rail to be used under severe environments, such as mining sites of natural resources, such as coal, is demanded to have high wear resistance and high toughness. Therefore, when the rail to be used under severe environments is manufactured, the above-described heat treatment process is required. However, when the rail manufactured by the process described above is subjected to processing, such as bending processing, for example, later, the processing becomes difficult to achieve in some cases because the rail is excessively hardened when subjected to heat treatment, so that the ductility decreases. Therefore, a rail with high hardness and excellent ductility has been demanded.

[0008] For example, JP 2013-14847 A discloses a method including setting the rolling temperature in finish rolling in a temperature range of Ar3 transformation point to 900°C, and then performing accelerated cooling of a rail to at least 550°C at a cooling rate of 2 to 30/sec within 150 sec after the end of the finish rolling to thereby increase the ductility of the rail.

[0009] Moreover, JP 62-127453 A discloses a method including performing rolling at an area reduction ratio of 10% or more in a temperature range 800°C or less in hot-rolling to thereby improve the ductility of a rail.

[0010] JP 2001234238 A discloses a producing method for a high toughness rail by which toughness is moreover imparted to steel with a pearlitic structure of high carbon excellent in strength and wear resistance by suppressing the growth of recrystallized fine grains γ in the process of rolling and after rolling. At the time of rolling steel containing 0.60 to 1.20% C into a rail, in finish rolling, continuous rolling in which rolling at a reduction of cross-sectional area by 5 to 30% per pass is applied for $\geq$2 passes, and the time between the rolling passes is $\leq$8 sec is performed at 850 to 1,000°C and the steel is successively cooled to 800 to 950°C at a cooling rate of 0.5 to 50°C/s and is thereafter subjected to air cooling or accelerated cooling.

[0011] WO 2005/085481 A1 discloses methods of producing steel rails having a high carbon content and being excellent in wear resistance and ductility from the slabs for rails. One method involves producing a steel rail having a high content of carbon, comprising finish rolling the rail in two consecutive passes, with a reduction rate per pass of a cross-section of the rail of 2-30%, wherein the conditions of the finish rolling satisfy the following relationship: $S \leq 800 / (C \times T)$, wherein S is the maximum rolling interval time (seconds), C is the carbon content of the steel, wherein the carbon content is 0.85-1.40 mass%, and T is the maximum surface temperature (°C) of the rail head. Another method involves producing a steel rail with a high content of carbon, comprising: finish rolling the rail in three or more passes, with a reduction rate per pass of a cross-section of the rail of 2-30%, wherein the conditions of the finish rolling satisfy the following relationship: $S \leq 2400 / (C \times T \times P)$, wherein S is the maximum rolling interval time (seconds), C is the carbon content of the steel rail, wherein the carbon content is 0.85~1.40 mass%, T is the maximum surface temperature (°C) of a rail head, and P is the number of passes, which is 3 or more. In addition to above, controlled additional amounts of V, Nb, N may be added to the steel rail and/or controlled rapid cooling of the rail after rolling may be accomplished to provide further improvements.

[0012] JP 2002 226 915 A discloses manufacturing method of a rail of high toughness in which the growth of re-crystallized grain y during an after rolling is suppressed, a pearlite structure of the grain is obtained, and the toughness is provided in steel representing pearlite structure with high carbon content of excellent strength and wear resistance. A steel slab containing, by mass, 0.6-1.20% C is subjected to rough rolling, and the intermediate rolling is performed by a reverse rolling mill at the surface temperature between 1,000 and 1, 050°C. The steel slab is subjected to the cooling immediately after the rolling of each pass of the intermediate rolling so that the temperature of the surface of a rail head and the surface of the bottom center is dropped by 50-100°C. Next, the finish rolling is performed by a continuous rolling mill at the surface temperature between 850 and 1,000°C with at least two passes of reduction ratio per pass of 5-30% and ≤10 seconds between rolling passes. After the rolling, the steel slab is cooled to 800-950°C at the cooling speed of 0.5-50°C/s on the rail surface, and subjected to the natural or accelerated cooling.

[0013] JP 5 472 418 B discloses a method to control the composition of steel, the reaction force ratio during finish rolling and the heat treatment condition after finish rolling, the structure of the head of the rail is made finer, the hardness is kept within a predetermined range, Improve abrasion and ductility. In mass%, C: 0.65 to 1.20%, Si: 0.05 to 2.00%, Mn: 0.05 to 2.00% are contained, the balance being Fe and unavoidable. A method for producing a pearlitic rail having excellent abrasion resistance and ductility by performing at least rough rolling and finish rolling on a steel strip for rail rolling made of impurities, characterized in that in the finish rolling, The amount of the unrecrystallized austenitic structure formed by rolling immediately after rolling in the temperature range of 900 ° C. or less to the A 3 transformation point or Ar cm transformation point is set to 40% or more and 70% or less in area ratio, Characterized in that the surface of the head of the rail after finish rolling is accelerated and cooled to at least 550 °C. at a cooling rate of 2 to 30 ° C./s within 150 seconds after completion of the finish rolling.

Summary of Invention

Problems to be Solved

[0014] However, the method described in Patent Document 1 has had a problem in that the temperature control for a foot portion of a rail is not performed, and therefore the ductility of the foot portion does not improve.

[0015] The method described in JP 62-127453 A has had a problem in that the temperature adjustment conditions in rolling for a foot portion of a rail are not specified, and therefore the ductility of the foot portion does not improve.

[0016] Then, the present invention has been made focusing on the problems described above. It is an object of the present invention to provide a method for manufacturing a rail having high ductility in both a head portion and a foot portion. Solution to the Problem

[0017] A method for manufacturing a rail according to the present invention is defined by claim 1. Dependent claims relate to preferred embodiments.

Advantageous Effects of the Invention

[0018] According to the method for manufacturing a rail according to the present invention, a rail having high ductility in both a head portion and a foot portion is able to be manufactured.

Brief Description of the Drawings

[0019]

FIG. 1 is a schematic view illustrating an apparatus for manufacturing a rail according to one embodiment of the present invention;
FIG. 2 is a cross-sectional view illustrating a rough cooling device that can be used when carrying out an embodiment of the method according to the present invention;
FIG. 3 is a schematic view illustrating a heat treatment apparatus that can be used when carrying out an embodiment of the method according to the present invention;
FIG. 4 is a cross-sectional view illustrating each portion of a rail;
FIG. 5 is an explanatory view illustrating collection positions of tensile test pieces evaluated in Examples; and
FIG. 6 is an explanatory view illustrating positions where a Brinell hardness test evaluated in Examples is carried out.

Description of Embodiments

[0020] Hereinafter, aspects for carrying out the present invention (hereinafter also referred to as "embodiment") are described in detail with reference to the drawings. In the following description, % for chemical composition means % by mass.

<Configuration of manufacturing apparatus>

[0021] First, a manufacturing apparatus 1 of a rail 9 that can be used when carrying out an embodiment of the method of the present invention is described with reference to FIG. 1 to FIG. 4. The rail manufacturing apparatus 1 according to this embodiment is a rolling line having a heating furnace 2, a roughing mill 3A, a finishing mill 3B, a rough cooling device 4, a finish cooling device 5, a re-heating device 6, a heat treatment apparatus 7, and a cooling bed 8.

[0022] The rail 9 is manufactured by rolling and heat-treating a steel rail material, such as a continuously cast bloom, by the manufacturing apparatus 1. As illustrated in FIG. 4, the rail 9 extends in the width direction viewed in a cross section perpendicular to the longitudinal direction and has a head portion 91 and a foot portion 93 facing each other in the vertical direction and an web portion 92 connecting the head portion 91 disposed on the upper side and the foot portion 93 disposed on the lower side and extending in the vertical direction. As the rail 9, steel containing the following chemical composition is usable, for example.

C: 0.60% or more and 1.05% or less

[0023] C (carbon) is an important element which forms cementite to increase hardness and strength and increases wear resistance in a pearlitic steel rail. However, when the content is less than 0.60%, these effects are low. Therefore, the lower limit is preferably set to 0.60% and more preferably set to 0.70% or more. On the other hand, excessive content of C causes an increase in the cementite amount, and therefore an increase in hardness and strength is expectable but, contrarily, the ductility decreases. The increase in the C content extends the temperature range of a $\gamma+\theta$ zone and promotes softening of a weld heat affected zone. Considering these adverse effects, the upper limit of the C content is preferably set to 1.05% and more preferably set to 0.97% or less.

Si: 0.1% or more and 1.5% or less

[0024] Si (silicon) is added as a deoxidizer and for reinforcing the pearlite structure. When the content is less than 0.1%, these effects are low. Therefore, the Si content is preferably 0.1% or more and more preferably 0.2% or more. On the other hand, excessive content of Si promotes decarburization and promotes the generation of surface flaws of the rail 9, and therefore the upper limit of the Si content is preferably set to 1.5% and more preferably 1.3% or less.

Mn: 0.01% or more and 1.5% or less

[0025] Mn (manganese) has an effect of lowering the pearlite transformation temperature and densifying the pearlite lamella intervals, and therefore Mn is effective for maintaining high hardness up to a rail inner region. When the content is less than 0.01%, the effect is low. Therefore, the Mn content is preferably 0.01% or more and more preferably 0.3% or more. On the other hand, when the Mn content exceeds 1.5%, the equilibrium transformation temperature (TE) of pearlite is lowered and martensite transformation easily occurs in the structure. Therefore, the upper limit of the Mn content is preferably set to 1.5% and more preferably set to 1.3% or less.

P: 0.035% or less

[0026] When the content of P (phosphorus) exceeds 0.035%, the toughness and the ductility are lowered. Therefore, the P content is preferably suppressed to 0.035% or less and more preferably limited to 0.025% or less. When special refinement and the like are performed in order to reduce the P content as much as possible, the cost increase in smelting is caused. Therefore, the lower limit is preferably set to 0.001%.

S: 0.030% or less

[0027] S (sulfur) extends in the rolling direction to form coarse MnS reducing ductility and toughness. Therefore, the S content is preferably suppressed to 0.030% or less and more preferably suppressed to 0.015% or less. In order to reduce the S content as much as possible, the cost increase in smelting, such as an increase in smelting processing time and a flux, is remarkable. Therefore, the lower limit is preferably set to 0.0005%.

Cr: 0.1% or more and 2.0% or less

[0028] Cr (chromium) increases the equilibrium transformation temperature (TE) and contributes to the reduction in the pearlite lamella intervals to increase the hardness and the strength. Furthermore, the use of Cr in combination with Sb is effective for inhibition of the generation of a decarburized layer. Therefore, when Cr is compounded, the content is preferably set to 0.1% or more and more preferably set to 0.2% or more. On the other hand, when the Cr content exceeds 2.0%, a possibility of the generation of welding defects increases, the quenching properties increase, and the generation of martensite is promoted. Therefore, the upper limit of the Cr content is preferably set to 2.0%, and more preferably set to 1.5% or less.

[0029] The total content of Si and Cr is desirably set to 2.0% or less. This is because, when the total content of Si and Cr exceeds 2.0%, the adhesiveness of a scale increases, and therefore the peeling of the scale may be inhibited and decarburization may be promoted.

Sb: 0.005% or more and 0.5 or less

[0030] When a steel rail material is heated with a heating furnace, Sb (antimony) has a remarkable effect of preventing decarburization during the heating. In particular, when Sb is added together with Cr, an effect of reducing a decarburized layer is demonstrated when the Sb content is 0.005% or more. Therefore, when Sb is compounded, the content is preferably 0.005% or more and more preferably 0.01% or more. On the other hand, when the Sb content exceeds 0.5%, the effect is saturated. Therefore, the upper limit is preferably set to 0.5% and more preferably set to 0.3% or less.

[0031] In addition to the chemical composition described above, one or two or more elements of Cu: 0.01% or more and 1.0% or less, Ni: 0.01% or more and 0.5% or less, Mo: 0.01% or more and 0.5% or less, V: 0.001% or more and 0.15% or less, and Nb: 0.001% or more and 0.030% or less may be compounded.

Cu: 0.01% or more and 1.0% or less

[0032] Cu (copper) is an element capable of further increasing the hardness by solid solution strengthening. Cu is effective also for decarburization control. In order to expect the effect, the Cu content is preferably 0. 01% or more and more preferably 0.05% or more. On the other hand, when the Cu content exceeds 1.0%, surface cracks due to embrittlement in continuous casting and rolling is easily generated. Therefore, the upper limit of the Cu content is preferably set to 1.0% and more preferably set to 0.6% or less .

Ni: 0.01% or more and 0.5% or less

[0033] Ni (nickel) is an element effective for increasing toughness and ductility. Moreover, by adding Ni in combination with Cu, Ni is an element effective also for preventing Cu cracks. Therefore, it is preferable to add Ni when adding Cu. However, when the Ni content is less than 0.01%, these effects are not obtained. Therefore, the lower limit is preferably set to 0.01% and more preferably set to 0.05% or more. On the other hand, when the Ni content exceeds 0.5%, hardenability excessively increases and the generation of a martensite is promoted. Therefore, the upper limit is preferably set to 0. 5% and more preferably set to 0.3% or less.

Mo: 0.01% or more and 0.5% or less

[0034] Mo (molybdenum) is an element effective for increasing strength. When the content is less than 0.01%, the effect is low. Therefore, the lower limit is preferably set to 0.01% and more preferably set to 0.05% or more. On the other hand, when the Mo content exceeds 0.5%, hardenability increases and a martensite is generated, and therefore the toughness and the ductility extremely decrease. Therefore, the upper limit of the Mo content is preferably set to 0.5% and more preferably set to 0.3% or less.

V: 0.001% or more and 0.15% or less

[0035] V (vanadium) is an element which forms VC, VN, or the like and is minutely precipitated into ferrite to contribute to an increase in the strength through precipitation strengthening of the ferrite. Moreover, V functions also as a trap site of hydrogen, and thus an effect of preventing delayed fracture is also expectable. To that end, the V content is preferably 0.001% or more and more preferably 0.005% or more. On the other hand, when V is added in a proportion exceeding 0.15%, the alloy cost extremely increases while the effects are saturated. Therefore, the upper limit is preferably set to 0.15% and more preferably set to 0.12% or less.

Nb: 0.001% or more and 0.030% or less

[0036] Nb (niobium) increases the non-recrystallization temperature of austenite and is effective for reducing the pearlite colony or block size by introduction of processing strain into the austenite in rolling. Therefore, Nb is an effective element for an improvement of ductility and toughness. In order to obtain the effect, the Nb content is preferably 0.001% or more and more preferably 0.003% or more. On the other hand, when the Nb content exceeds 0.030%, Nb carbonitride is crystallized in a solidification process in casting of a steel rail material to reduce cleanliness. Therefore, the upper limit is preferably set to 0.030% and more preferably set to 0.025% or less.

[0037] The remainder other than the components described above includes Fe (iron) and inevitable impurities. As the inevitable impurities, the mixing of N (nitrogen) up to 0.015%, the mixing of O (oxygen) up to 0.004%, and the mixing of H (hydrogen) up to 0.0003% are acceptable. In order to prevent a reduction in rolling fatigue properties due to hard AlN or TiN, the Al content is desirably set to 0.001% or less and the Ti content is desirably set to 0.001% or less.

[0038] The heating furnace 2 is a continuation type or batch type heating furnace and heats steel rail materials, such as a continuously cast bloom, to a predetermined temperature.

[0039] The roughing mill 3A is a universal mill which hot-rolls a steel material at a predetermined area reduction ratio and two or more of the roughing mills 3A are provided. In the example illustrated in FIG. 1, the manufacturing apparatus 1 has n pieces of roughing mills 3A1 to 3An. The rough cooling device 4 is provided between a k-th roughing mill 3Ak and a (K+1) -th roughing mill 3Ak+1 among the roughing mills 3A1 to 3An along the conveyance direction of the rail 9.

[0040] The finishing mill 3B is a universal mill which further hot-rolls the rough-rolled rail 9 to thereby finally process the same into a target rail shape. In this embodiment, the area reduction ratio of the rail 9 to be rolled from the (k+1)-th roughing mill 3Ak+1 to the finishing mill 3B as the rolling process after the rough cooling device 4 is set to 20% or more. Herein, the area reduction ratio in this embodiment shows the area reduction ratio of a cross-sectional area perpendicular to the longitudinal direction of the steel rail material and shows the ratio of the reduction in the cross-sectional area during the rolling to the cross-sectional area before the rolling of the bloom and the like.

[0041] The rough cooling device 4 has a head portion cooling nozzle 41, a foot portion cooling nozzle 42, a head portion thermometer 43, a foot portion thermometer 44, a conveyance table 45, guides 46a and 46b, and a control unit 47 as illustrated in FIG. 2.

[0042] The head portion cooling nozzle 41 cools the head portion 91 of the rail 9 by ejecting a cooling medium to the head portion 91. The foot portion cooling nozzle 42 cools the foot portion 93 of the rail 9 by ejecting a cooling medium to the foot portion 93. The cooling medium ejected from the head portion cooling nozzle 41 and the foot portion cooling nozzle 42 is spray water. The head portion cooling nozzle 41 and the foot portion cooling nozzle 42 are provided above the head portion 91 and the foot portion 93, respectively, on the y-axis positive direction side and eject a cooling medium to each of the head portion 91 and the foot portion 93 with an inclination with respect to the y axial direction. Moreover, two or more of the head portion cooling nozzles 41 and the foot portion cooling nozzles 42 are provided along the z axis direction perpendicular to the x-y plane as the longitudinal direction of the rail 9.

[0043] The head portion thermometer 43 and the foot portion thermometer 44 are noncontact thermometers which measure the surface temperature of each of the head portion 91 and the foot portion 93 of the rail 9, respectively, to which the cooling medium is ejected and are provided facing the head portion 91 and the foot portion 93, respectively, in the x axis direction. The measurement results of the head portion thermometer 43 and the foot portion thermometer 44 are transmitted to the control unit 47.

[0044] The conveyance table 45 is a conveyance roll extending in the x axis direction and two or more of the conveyance tables 45 are provided side by side along the z axis direction. The guides 46a and 46b are plate-like members and are provided extending in the z axis direction. The guides 46a and 46b are individually disposed on the upper side relative to the conveyance table 45 on the y-axis positive direction side and on both end sides in the longitudinal direction of the conveyance table 45. Furthermore, the guides 46a and 46b are further provided with openings 461a and 461b at the positions where the head portion thermometer 43 and the foot portion thermometer 44 are disposed, respectively.

[0045] The control unit 47 controls the conditions of the cooling medium ejected from the head portion cooling nozzle 41 and the foot portion cooling nozzle 42 based on the measurement results of the head portion thermometer 43 and the foot portion thermometer 44 to thereby cool the rail 9 to a predetermined surface temperature. The ejection conditions of the cooling medium include the ejection amount, the ejection pressure, the moisture amount, the ejection time, and the like of the cooling medium, for example.

[0046] The rough cooling device 4 of the configuration described above is provided between the k-th roughing mill 3Ak and the (k+1) -th roughing mill 3Ak+1 among the plurality of roughing mills 3A located side by side in the rolling direction of the rail 9 and controls the surface temperature of the head portion 91 and the foot portion 93 of the rail 9 to be rolled with the k-th roughing mill 3Ak.

[0047] The finish cooling device 5 is provided immediately before the finishing mill 3B and controls the surface temperature of the head portion 91 and the foot portion 93 of the rail 9 to be rolled with the finishing mill 3B. The finish cooling device 5 has the same configuration as that of the rough cooling device 4 illustrated in FIG. 2.

[0048] The rail 9 is conveyed and rolled with an overturned state as illustrated in FIG. 2 when rolled or cooled with the roughing mills 3A, the rough cooling device 4, the finish cooling device 5, and the finishing mill 3B.

[0049] The re-heating device 6 is an induction heating type heating device and heats the head portion 91 of the rail 9 to a predetermined temperature.

[0050] The heat treatment apparatus 7 has head portion cooling headers 71a to 71c, a foot portion cooling header 72, a head portion thermometer 73, and a control unit 74 as illustrated in FIG. 3. The head portion cooling headers 71a to 71c are provided facing each of the head top surface and both head side surfaces of the head portion 91 and cool the head portion 91 by ejecting a cooling medium to the head top surface and both the head side surfaces. The foot portion cooling header 72 is provided facing the underside of the foot portion 93 and cools the foot portion 93 by ejecting a cooling medium to the underside of the foot. For the cooling medium ejected from the head portion cooling headers 71a to 71c and the foot portion cooling header 72, air, water, mist, and the like are used. Two or more of the head portion cooling headers 71a to 71c and the foot portion cooling headers 72 are provided side by side along the longitudinal direction of the rail 9. The head portion thermometer 73 is a non-contact-type thermometer and measures the surface temperature of the head portion 91. The temperature measurement results of the head portion thermometer 73 are transmitted to the control unit 74. The control unit 74 controls the ejection conditions of the cooling medium ejected from the head portion cooling headers 71a to 71c and the foot portion cooling header 72 according to the temperature measurement results of the head portion thermometer 73 to thereby control the cooling rate of the rail 9. The heat treatment apparatus 7 of the configuration described above cools the rail 9 at a predetermined cooling rate until the surface temperature reaches a predetermined surface temperature. The heat treatment apparatus 7 has a clamp (not illustrated). The clamp is a device restraining the foot portion of the rail 9 by holding the same.

[0051] The cooling bed 8 is a device which naturally cools the rail 9 and contains, for example, a base supporting the rail 9.

<Rail manufacturing method>

[0052] Next, a method for manufacturing the rail 9 according to one embodiment of the present invention is described.

[0053] First, a bloom which is a steel rail material cast by a continuous casting method is carried into the heating furnace 2 to be heated to reach 1100°C or more.

[0054] Subsequently, the heated steel rail material is rolled to have an almost rail shape by the roughing mills 3Aa to 3Ak on the upstream side in the conveyance direction relative to the rough cooling device 4. Hereinafter, a steel material in the hot-rolling process is also referred to as a steel rail material.

[0055] Furthermore, the steel rail material rolled with the roughing mills 3Aa to 3Ak is cooled (temperature adjustment) with the rough cooling device 4 until the surface temperature of portions corresponding to the head portion 91 and the foot portion 93 of the rail 9 reaches 500°C or more and 1000°C or less. Herein, the control unit 47 controls the ejection amount, the ejection pressure, the moisture amount, the ejection time, and the like of the cooling medium to thereby cool the steel rail material.

[0056] When the steel rail material is heated to 1100°C or more, the entire structure is transformed into austenite. In the austenite structure of 1000°C or more, the grain boundary easily moves and re-crystallization occurs, so that the crystal grains are coarsened. On the other hand, when the rolling is performed, strain is generated in the crystal grains, and thus the crystal grains are divided, and then refined. Herein, when the temperature in the rolling is 1000°C or less, the re-crystallization and the coarsening of the crystal grains are difficult to occur. Therefore, by setting the temperature of the steel rail material in the rolling to 1000°C or less, the coarsening of the crystal grains refined by the rolling is difficult to occur.

[0057] When the steel rail material is cooled with the rough cooling device 4, the temperature adjustment is preferably performed until the surface temperature of the portions corresponding to the head portion 91 and the foot portion 93 reach 500°C or more and 730°C or less. When the steel rail material is cooled to 730°C or less, the structure partially causes pearlite transformation. Therefore, the structure of the steel rail material has a two phase structure containing untransformed austenite and pearlite. When the austenite and the pearlite are compared with each other, the yield strength of the austenite is lower, and therefore most of strain is introduced in the austenite grains and the structure in the rolling is refined as compared with the case where the structure in the rolling is an austenite single phase. The colony size and the block size of the pearlite as the final structure are affected by the crystal grain diameter of the austenite which is the structure before transformation. Therefore, when the austenite grains are coarse, the colony size and the block size of the pearlite are also coarsened, and therefore the ductility decreases. On the other hand, when the austenite grains are fine, the colony size and the block size of the pearlite are refined, and therefore the ductility improves.

[0058] When the temperature of the rail 9 in the rolling reaches less than 500°C, the structure completely causes pearlite transformation, and therefore the austenite grains are not present. Therefore, the colony size and the block size of the pearlite do not become smaller, and thus an improvement of ductility cannot be expected.

[0059] The phenomenon described above occurs irrespective of portions of the rail 9. Therefore, by performing the rolling after the temperature adjustment is performed in the portions corresponding to the head portion 91 and the foot portion 93, toughness and ductility is improved.

[0060] Thereafter, the steel rail material subjected to the temperature adjustment with the rough cooling device 4 is further rolled with the roughing mills 3Ak+1 to 3An.

[0061] Subsequently, the steel rail material rough-rolled with the roughing mills 3A1 to 3An is cooled with the finish cooling device 5 as necessary, and then rolled with the finishing mill 3B to be formed into the rail 9 of a desired shape. The rolling in the roughing mills 3Ak+1 to 3An and the finishing mill 3B after the temperature adjustment is also referred to as temperature-adjusted rolling. The area reduction ratio of the steel rail material to be subjected to the temperature-adjusted rolling is 20% or more. By setting the area reduction ratio to 20% or more, strain can be generated also in the steel rail material, and therefore the inside structure of the rail 9 can be refined. On the other hand, when the area reduction ratio is less than 20%, a large number of strains are generated in the surface of the steel rail material but the number of strains generated inside the steel rail material decreases. Therefore, the refinement of the inside structure of the rail 9 becomes difficult to achieve, so that a ductility improvement degree decreases.

[0062] Furthermore, the rail 9 hot-rolled with the roughing mills 3A and the finishing mill 3B is conveyed to the re-heating device 6 to be heated until the surface temperature of the head portion 91 reaches 730°C or more and 900°C or less.

[0063] Thereafter, the heated rail 9 is conveyed to the heat treatment apparatus 7 to be forcibly cooled (heat treatment) with the heat treatment apparatus 7 in the state of being restrained by the clamp until the surface temperature of the head portion 91 reaches 600°C or less. Herein, the control unit 74 calculates the cooling rate of the rail 9 from the temperature measurement results of the head portion thermometer 73, and then controls the ejection conditions of the cooling medium ejected from the head portion cooling headers 71a to 71c so that the average cooling rate is 1°C/s or more and 10°C/s or less. Moreover, the control unit 74 controls the ejection conditions of the cooling medium ejected from the foot portion cooling header 72 in such a manner as to be the same as any one of the ejection conditions of the cooling medium ejected from the head portion cooling headers 71a to 71c.

[0064] When the surface temperature of the head portion 91 is less than 730°C before the heat treatment, the structure partially or entirely causes pearlite transformation. Before the heat treatment, the rail 9 is naturally cooled and the cooling rate is low. Therefore, the pearlite lamella intervals is coarse. Therefore, by performing re-heating so that the surface temperature of the head portion 91 reaches 730°C or more before the heat treatment, the pearlite structure is reversely transformed to the austenite structure, and thus the lamella structure is able to be formed again. On the other hand, when the surface temperature of the head portion 91 is higher, the hardening of the decarburized layer on the surface and the hardening due to an improvement of the cooling rate inside the rail are achieved, so that the wear resistance is improved. However, when the surface temperature of the head portion 91 exceeds 900°C, the effect described above is lowered. Furthermore, when the surface temperature of the head portion 91 exceeds 1000°C, the re-crystallization and the coarsening of the austenite grains occur, which is not preferable. Therefore, considering the saving of the energy required for the re-heating and the wear resistance improvement effect, the upper limit of the surface temperature in the re-heating before the heat treatment is preferably set to 900°C.

[0065] In order to achieve high wear resistance properties, the reduction in the pearlite lamella intervals is effective. In order to reduce pearlite lamella intervals, heat treatment at a high cooling rate is required. Therefore, the heat treatment is preferably performed at a surface temperature and at an average cooling rate within the ranges mentioned. When the cooling rate is less than 1°C/s, the pearlite lamella intervals are coarse and the wear resistance decreases. On the other hand, when the cooling rate exceeds 10°C/s, the structure after transformation is such as bainite and martensite that are poor in toughness and ductility, and this is not preferable. In this embodiment, the average cooling rate is a cooling rate determined from the temperature changes and the heat treatment time from the start of the heat treatment to the end of the heat treatment. Therefore, the thermal history from the start of the heat treatment to the end of the heat treatment also includes the heat generation of the phase transformation heat and isothermal-holding by patenting treatment. When the surface temperature of the head portion 91 at the end of the heat treatment exceeds 600°C, the lamella structure is partially spheroidized after the end of the heat treatment, and therefore the lamella intervals are coarse and the wear resistance decreases.

[0066] Subsequently, the rail 9 subjected to accelerated cooling is conveyed to the cooling bed 8, and then naturally cooled until the temperature reaches about 100°C or less. After the cooling on the cooling bed 8, shape correction of the rail 9 is performed as necessary when the rail 9 is bent or the like. By passing through the processes described above, the rail 9 excellent in ductility and wear resistance is manufactured.

<Modification>

[0067] Hitherto, the preferable embodiments of the present invention are described in detail with reference to the accompanying drawings but the present invention is not limited to such examples. It is apparent that a person who has ordinary knowledge in the technical field to which the present invention belongs can perceive various changes or modifications within the scope of the technical thoughts described in claims. It should be understood that these changes or modifications also naturally belong to the technical scope of the present invention.

[0068] For example, the cooling method in the rough cooling device 4 and the finish cooling device 5 is spray cooling employing spray water for the cooling medium in the embodiment described above but the present invention is not limited to the example. For example, mist cooling as spray cooling employing mist as a cooling medium or mixed cooling of mist cooling and air blast cooling employing mist and air as a cooling medium may be used for the cooling method in the rough cooling device 4 and the finish cooling device 5. Alternatively, natural cooling, immersion cooling, air blast cooling, water column cooling, and the like may be performed in place of the spray cooling with the rough cooling device 4 and the finish cooling device 5. In the natural cooling and the air blast cooling, the cooling rate is low, and therefore the time until the rail 9 is cooled to a predetermined temperature is prolonged. Therefore, when the rolling pitch is to be increased, other cooling methods, such as spray cooling, immersion cooling, and water column cooling, are able to be employed. However, the cooling rate in the water column cooling is excessively high, and therefore the cooling rate is difficult to adjust. Furthermore, when the rail 9 is conveyed with an overturned state, water is stored in the web portion 92 of the rail 9, resulting in the generation of a portion with an excessively high cooling rate. Therefore, the structure may be transformed to a structure having low toughness and ductility, such as bainite and martensite. On the other hand, the spray cooling has advantages in that a somewhat high cooling rate is able to be secured and the cooling portion is easily localized. Therefore, the spray cooling is preferably used for the cooling method in the rough cooling device 4 and the finish cooling device 5.

[0069] Furthermore, the temperature-adjusted rolling is performed in the rolling pass after the roughing mill 3Ak+1 in the embodiment described above but the present invention is not limited to the example. The temperature-adjusted rolling may be performed after any roughing mill 3A insofar as an area reduction ratio of 20% or more is able to be secured. Herein, the rough cooling device 4 is provided immediately before the roughing mill 3A with which the temperature-adjusted rolling is started. The temperature-adjusted rolling may be performed in finish rolling by the finishing mill 3B. Herein, the rough cooling device 4 may not be provided in the rail manufacturing apparatus 1 and the temperature adjustment may be performed only the finish cooling device 5. When the temperature-adjusted rolling is performed in finish rolling, the finish rolling needs to be performed at a large area reduction ratio of 20% or more, and therefore the shape of the rail 9 may deteriorates. Therefore, the temperature-adjusted rolling is preferably performed in the rolling with some of the roughing mills 3A and with the finishing mill 3B.

[0070] Furthermore, the roughing mills 3A and the finishing mill 3B are universal mills in the embodiment described above but the present invention is not limited to the example. For example, the roughing mills 3A and the finishing mill 3B may be caliber rolling mills. In a universal rolling method, rolling from a plurality of directions is achieved as compared with a caliber rolling method, and therefore the rolling load can be reduced. In particular, in the present invention, a rolling operation capable of obtaining a large area reduction ratio at a low temperature is performed, and therefore rolling is performed under an overload and the load to the rolling mills becomes high, so that the risk of a facility trouble becomes high. Therefore, at least any one of the roughing mills 3A and two or more of the finishing mills 3B is preferably a universal mill.

[0071] Furthermore, two or more of the finishing mills 3B may be provided.

[0072] Furthermore, the re-heating device 6 is the induction heating type heating device in the embodiment described above but the present invention is not limited to the example. For example, the re-heating device 6 may be a burner type heating device. In the induction heating type re-heating device 6, the size of the facility is able to be made small as compared with the burner type. Therefore, the induction heating type re-heating device 6 is preferable when disposed in-line.

[0073] The re-heating device 6 heats the head portion 91 in the embodiment described above but the present invention is not limited to the example. For example, the re-heating device 6 may have a configuration of heating the entire rail 9. When the rail 9 is used, portions contacting wheels are worn out, and therefore particularly the head portion 91 is required to have wear resistance. Therefore, a configuration of re-heating only the head portion 91 in re-heating is economically excellent because energy required for the heating is able to be reduced.

[0074] Furthermore, the re-heating is performed with the re-heating device 6 after the hot-rolling in the embodiment described above but the re-heating with the re-heating device 6 may not be performed. Herein, the hot-rolled rail 9 is conveyed to the heat treatment apparatus 7, and then heat-treated with the heat treatment apparatus 7. Even when the re-heating is not performed, the ductility improvement effect of the head portion 91 and the foot portion 93 is able to be obtained. However, when the temperature of the rail 9 after the end of the hot-rolling (after the end of the temperature-adjusted rolling) is low, the hardness decreases as compared with the case where the temperature is high. Herein, the hot-rolled rail 9 is conveyed to the cooling bed 8, and then cooled until the temperature reaches about 100°C or less. Even when the re-heating and the heat treatment are not performed, the ductility improvement effect of the head portion 91 and the foot portion 93 is able to be obtained. However, the hardness decreases as compared with the case where the re-heating and the heat treatment are performed.

<Advantageous effects of embodiment>

[0075]

(1) The method for manufacturing the rail 9 according to the embodiment described above includes hot-rolling a heated steel rail material, adjusting the temperature by cooling the hot-rolled steel rail material, processing the steel rail material subjected to the temperature adjustment into a rail shape by means of temperature-adjusted rolling at an area reduction ratio of 20% or more, and, in adjusting the temperature of the steel rail material, cooling the surface portions of the steel rail material corresponding to a head portion and a foot portion of the rail shape so that the temperatures of the surface portions reach 500°C or more and 1,000°C or less.
According to the configuration described above, crystal grains are able to be divided and refined while preventing the coarsening of the crystal grains due to the re-crystallization in the austenite temperature range in the temperature-adjusted rolling. Therefore, the toughness and the ductility of the head portion 91 and the foot portion 93 of the rail 9 are able to be increased.
(2) After performing the temperature-adjusted rolling, the rail 9 is heat-treated until the surface temperature of the head portion of the rail 9 reaches 600°C or less at an average cooling rate of 1 °C/s or more and 10 °C/s or less.
According to the configuration described above, the pearlite lamella intervals of the head portion 91 of the rail 9 can be refined and the wear resistance is able to be increased. Moreover, the spheroidization of the lamella structure after the end of the heat treatment is able to be prevented, and therefore the wear resistance improves.
(3) Before heat-treating the rail 9, the rail may be re-heated to 730°C or more when the surface temperature of the head portion of the rail 9 is less than 730°C.
According to the configuration described above, the pearlite structure is able to be reversely transformed to the austenite structure, so that the lamella structure is able to be re-created again. Therefore, the hardness and the wear resistance of the rail 9 are able to be increased.
(4) In re-heating the rail 9, only the head portion 91 of the rail 9 is re-heated.
According to the configuration described above, the energy required for the heating is able to be reduced as compared with the case where the entire rail 9 is re-heated.
(5) The apparatus 1 for manufacturing the rail 9 according to the embodiment has at least one first rolling mills 3A1 to 3AK rolling a steel rail material, a cooling device 4 adjusting a temperature by cooling the steel rail material rolled with the first rolling mills 3A1 to 3AK, and at least one second rolling mills 3AK+1 to 3An and 3B processing the steel rail material subjected to the temperature adjustment into a rail shape by means of temperature-adjusted rolling at an area reduction ratio of 20% or more, in which the cooling device 4 cools the surface portions of the steel rail material corresponding to the head portion 91 and the foot portion 93 of the rail shape so that the temperatures of the surface portions reach 500°C or more and 1,000°C or less.

[0076] According to the configuration described above, the same effects as those obtained in (1) are able to be obtained. Examples

[Example 1]

[0077] Next, Examples 1 performed by the present inventors are described.
[0078] In Examples 1, rails 9 were manufactured using the rail manufacturing apparatus 1 described in FIG. 1 under various chemical composition conditions and rolling conditions, and then the total elongation of the manufactured rails 9 was measured.
[0079] Table 1 shows the chemical composition of the rail 9 used in Examples 1. The remainder includes iron and inevitable impurities. Table 2 shows the rolling conditions and the measurement results of the total elongation in Examples 1.

[Table 1]

Composition	C[%]	Si [%]	Mn [%]	P[%]	S[%]	Cr[%]	Sb [%]	Al [%]	Ti [%]	Others
A	0.83	0.52	0.51	0.015	0.008	0.192	0.0001	0.0005	0.001	
B	0.83	0.52	1.11	0.015	0.008	0.192	0.0001	0.0005	0.001	
C	1.03	0.52	1.11	0.015	0.008	0.192	0.0001	0.0005	0.001	
D	0.84	0.54	0.55	0.018	0.004	0.784	0.0001	0.0000	0.002	V[%]: 0.058

(continued)

Composition	C[%]	Si [%]	Mn [%]	P[%]	S[%]	Cr[%]	Sb [%]	Al [%]	Ti [%]	Others
E	0.82	0.23	1.26	0.018	0.005	0.155	0.0360	0.0001	0.001	
F	0.83	0.66	0.26	0.015	0.005	0.896	0.1200	0.0005	0.001	Cu [%] : 0.11, Ni [%] : 0.12, Mo[%] : 0.11
G	0.82	0.55	1.13	0.012	0.002	0.224	0.0001	0.0000	0.000	Nb[%] : 0.009

[Table 2]

Condition	Composition	Temperature adjustment method	Time from temperature-adjusted rolling to end of finish rolling [s]	Number of temperature-adjusted rolling passes	At start of temperature-adjusted rolling		In temperature-adjusted rolling		Total elongation of head portion [%]	Total elongation of foot portion [%]
					Head portion temperature [°C]	Foot portion temperature [°C]	Head portion area reduction ratio [%]	Foot portion area reduction ratio [%]		
Ex. 1-1	A	Spray cooling	20	4	950	900	30	30	14	13
Ex. 1-2	B	Spray cooling	5	4	950	900	30	30	14	13
Ex. 1-3	C	Spray cooling	30	5	950	900	30	30	12	12
Ex. 1-4	A	Natural cooling	20	2	950	900	30	30	14	13
Ex. 1-5	A	Air blast cooling	10	2	950	900	30	30	14	13
Ex. 1-6	A	Spray cooling	0	1	950	900	30	30	14	13
Ex. 1-7	A	Spray cooling	1	2	950	900	30	30	14	13
Ex. 1-8	A	Spray cooling	20	3	500	500	30	30	20	19
Ex. 1-9	A	Natural cooling	5	2	950	900	30	30	14	13
Ex. 1-10	A	Air blast cooling	30	5	950	900	30	30	14	13
Ex. 1-11	A	Spray cooling	30	3	990	900	30	30	12	13
Ex. 1-12	A	Spray cooling	20	4	850	900	30	30	15	13
Ex. 1-13	A	Spray cooling	10	3	750	900	30	30	15	13
Ex. 1-14	A	Spray cooling	0	1	650	900	30	30	18	13
Ex. 1-15	A	Spray cooling	30	4	500	900	30	30	20	13
Ex. 1-16	A	Spray cooling	40	4	950	990	30	30	14	12
Ex. 1-17	A	Spray cooling	30	3	950	950	30	30	14	12
Ex. 1-18	A	Spray cooling	20	4	950	750	30	30	14	14

(continued)

Condition	Composition	Temperature adjustment method	Time from temperature-adjusted rolling to end of finish rolling [s]	Number of temperature-adjusted rolling passes	At start of temperature-adjusted rolling		In temperature-adjusted rolling		Total elongation of head portion [%]	Total elongation of foot portion [%]
					Head portion temperature [°C]	Foot portion temperature [°C]	Head portion area reduction ratio [%]	Foot portion area reduction ratio [%]		
Ex. 1-19	A	Spray cooling	20	5	950	650	30	30	14	17
Ex. 1-20	A	Spray cooling	15	4	950	500	30	30	14	19
Ex. 1-21	A	Natural cooling	30	6	950	900	20	30	12	13
Ex. 1-22	A	Natural cooling	40	5	950	900	25	30	13	13
Ex. 1-23	A	Spray cooling	20	4	950	900	30	20	14	12
Ex. 1-24	A	Natural cooling	50	6	950	900	30	30	14	12
Ex. 1-25	D	Spray cooling	25	4	950	900	30	30	14	13
Ex. 1-26	E	Spray cooling	25	3	950	900	30	30	14	13
Ex. 1-27	F	Spray cooling	25	5	950	900	30	30	14	13
Ex. 1-28	G	Spray cooling	25	4	950	900	30	30	14	13
Comp. Ex. 1-1	A	Spray cooling	20	2	850	1020	30	30	14	11
Comp. Ex. 1-2	A	Spray cooling	60	4	850	900	30	10	14	10
Comp. Ex. 1-3	A	Spray cooling	20	2	400	900	30	30	10	13
Comp. Ex. 1-4	A	Spray cooling	45	2	1020	900	30	30	11	13
Comp. Ex. 1-5	A	Spray cooling	15	4	950	900	10	30	10	13

[0080] In Examples 1, first, a continuously cast bloom was heated with the heating furnace 2 until the temperature reached 1100°C. The chemical composition of the bloom used in Examples 1 was any one of the composition A to the composition G of Table 1 as shown in Table 2.

[0081] Subsequently, the heated bloom was collected from the heating furnace 2, and then hot-rolled with the roughing mills 3A and the finishing mill 3B. For the roughing mills 3A, a plurality of rolling mills in which a universal mill and a caliber rolling mill were combined was used. The rail 9 during the rolling was rolled and conveyed with an overturned state. When the hot-rolling was performed, the temperature adjustment was performed until the surface temperatures of the head portion 91 and the foot portion 93 reached 500°C or more and 1000°C or less with either the rough cooling device 4 or the finish cooling device 5. The temperature adjustment method, the time from the start of the temperature-adjusted rolling to the end of the hot-rolling, and the number of temperature-adjusted rolling passes are individually shown in Table 2. The temperature-adjusted rolling refers to hot-rolling after the temperature adjustment was performed.

[0082] As shown in Table 2, in Examples 1, the temperature adjustment was performed by any one of the spray cooling, air blast cooling, and naturally cooling methods. The surface temperatures of the head portion 91 and the foot portion 93 were adjusted by adjusting the water amount density and the cooling time in the case of the spray cooling or by controlling the cooling time without using the rough cooling device 4 and the finish cooling device 5 in the case of the natural cooling.

[0083] The number of the temperature-adjusted rolling passes shown in Table 2 shows the number of rolling passes after the temperature adjustment was performed by any one of the methods described above. For example, the number of times of the temperature-adjusted rolling passes was 1 time indicates that, after the temperature adjustment, only the finish rolling was performed and the number of times of the temperature-adjusted rolling passes was n ($n \geq 2$) times indicates that, after the temperature adjustment, n-1 times of rough rolling and one finish rolling were performed. When the number of times of the temperature-adjusted rolling passes was 1 time, the temperature adjustment was performed using the finish cooling device 5. When the number of times of the temperature-adjusted rolling passes was n times, the temperature adjustment was performed using the rough cooling device 4.

[0084] After the hot-rolling was performed, the rail 9 was forcibly cooled with the heat treatment apparatus 7. The surface temperatures of the head portion 91 and the foot portion 93 in starting the forcible cooling were set as shown in the conditions shown in Table 2. When the forcible cooling was performed, the average cooling rate was set to 3°C/s. The cooling was performed until the surface temperature reached 400°C. When the forcible cooling was performed, mist was used for a cooling medium. In Examples 1, the re-heat treatment employing the re-heating device 6 was not performed after the hot-rolling.

[0085] Subsequently, the forcibly cooled rail 9 was conveyed to the cooling bed 8, the temperature was reduced to 100°C or less by cooling, and then the rail was straightened. After the rail 9 was manufactured in the processes described above, test pieces were collected from four places of an end portion, the 1/4 position, the 1/2 position, and the 3/4 position in the longitudinal direction of the rail 9, and then various physical properties were measured. As illustrated in FIG. 5, a sample 9a was collected from the head portion 91 and a sample 9b was collected from the foot portion 93 of the test pieces collected at each position in the longitudinal direction. The sample 9a is a JIS No. 4 test piece collected from a position having a distance d2 = 12.7 mm from the upper end of the head portion 91 and having a distance d1 = 24.6 mm from the center in the width direction. The sample 9b is a JIS No. 4 test piece collected from a position having a distance d3 = 12.7 mm from the lower end of the foot portion 93 and at the center in the width direction.

[0086] In Examples 1, as examples different in the chemical composition, the temperature adjustment method, the number of temperature-adjusted rolling passes, the surface temperature, and the area reduction ratio, rails 9 were manufactured under 28 kinds of conditions of Examples 1-1 to 1-28, and then the total elongation was evaluated.

[0087] Moreover, as shown in Table 2, rails 9 were manufactured as comparative examples under the same conditions as those of Examples 1-1 to 1-28, and then the total elongation was evaluated also for Comparative Examples 1-1 to 1-5 with the surface temperature and the area reduction ratio in the temperature-adjusted rolling outside the ranges of the embodiment described above. The total elongation values shown in Table 2 show the average value of the four samples, i.e., the sum of one sample collected from each of the test pieces collected from each of the four places.

[0088] It was confirmed that the total elongations of the head portion 91 and the foot portion 93 were 12% or more as the target total elongation under all the conditions of Examples 1-1 to 1-28. It was also confirmed that, in Examples 1-14, 1-15, 1-19, and 1-20 in which the surface temperature of either the head portion 91 or the foot portion 93 was 730°C or less in the temperature-adjusted rolling, the elongation of the head portion 91 or the foot portion 93 with a low surface temperature was as high as 17% or more. Furthermore, it was confirmed that, in Example 1-8 in which the surface temperatures of both the head portion 91 and the foot portion 93 in the temperature-adjusted rolling were 730°C or less, the total elongations of the head portion 91 and the foot portion 93 were as high as 19% or more.

[0089] On the other hand, in Comparative Example 1-1 in which the surface temperature of the foot portion 93 in the temperature-adjusted rolling exceeded 1000°C and Comparative Example 1-2 in which the area reduction ratio of the foot portion 93 in the temperature-adjusted rolling was less than 20%, the elongation of the foot portion 93 was less than 12% and decreased as compared with those of Examples 1-1 to 1-28. In Comparative Examples 1-3 and 1-4 in which the surface temperature in the temperature-adjusted rolling was less than 500°C or exceeded 1000°C and Comparative Example 1-5 in which the rolling reduction of the head portion 91 in the temperature-adjusted rolling was less than 20%, the elongation of the head portion 91 was less than 12% and decreased as compared with those of Examples 1-1 to 1-28.

[Example 2]

[0090] Next, Examples 2 performed by the present inventors are described.

[0091] In Examples 2, influences on the total elongation, the hardness, and the surface structure depending on the heat treatment conditions were confirmed by varying the chemical composition and the conditions in the temperature-adjusted rolling and the heat treatment. Table 3 shows the chemical composition, the surface temperature in temperature-adjusted rolling, the conditions of heat treatment (forcible cooling), the measurement results of the total elongation, the measurement results of the hardness, and the observation results of a head portion surface structure in Examples 2.

[Table 3]

Condition	Composition	In temperature-adjusted rolling		In heat treatment			Total elongation		Hardness		Head portion surface structure
		Head portion temperature [°C]	Foot portion temperature [°C]	Start temperature [°C]	Cooling rate [°C/s]	End temperature [°C]	Head portion [%]	Foot portion [%]	Head portion surface [HB]	Head portion inner region [HB]	
Ex. 2-1	A	950	900	890	3	400	14	13	410	380	Fine pearlite
Ex. 2-2	A	850	900	800	3	400	15	13	408	370	Fine pearlite
Ex. 2-3	A	650	900	630	3	400	18	13	380	360	Coarse pearlite
Ex. 2-4	A	950	950	890	3	400	14	13	410	380	Fine pearlite
Ex. 2-5	A	950	750	890	3	400	14	14	410	380	Fine pearlite
Ex. 2-6	A	950	650	5	3	400	14	17	410	380	Fine pearlite
Ex. 2-7	A	950	900	890	0.5	400	14	13	375	345	Coarse pearlite
Ex. 2-8 Ex.	A	950	900	890	1	400	14	13	390	355	Fine pearlite
2-9	A	950	900	890	5	400	14	13	420	385	Fine pearlite
Ex. 2-10	A	950	900	890	10	400	14	13	440	400	Fine pearlite
Ex. 2-11	A	950	900	890	3	650	14	13	380	355	Partially spheroidized pearlite
Ex. 2-12	A	950	900	890	3	500	14	13	400	370	Fine pearlite
Ex. 2-13	A	950	900	-	-	-	14	13	350	340	Partially spheroidized pearlite
Ex. 2-14	B	950	900	890	0.5	400	14	13	430	380	Fine pearlite
Ex. 2-15	B	950	900	890	3	400	14	13	465	395	Fine pearlite
Ex. 2-16	C	950	900	890	0.5	400	12	12	460	395	Fine pearlite
Ex. 2-17	C	950	900	890	3	400	12	12	485	410	Fine pearlite

(continued)

Condition	Composition	In temperature-adjusted rolling		In heat treatment			Total elongation		Hardness		Head portion surface structure
		Head portion temperature [°C]	Foot portion temperature [°C]	Start temperature [°C]	Cooling rate [°C/s]	End temperature [°C]	Head portion [%]	Foot portion [%]	Head portion surface [HB]	Head portion inner region [HB]	
Ex. 2-18	D	950	900	890	3	400	14	13	485	410	Fine pearlite
Ex. 2-19	E	950	900	890	3	400	14	13	410	375	Fine pearlite
Ex. 2-20	F	950	900	890	3	400	14	13	420	377	Fine pearlite
Ex. 2-21	G	950	900	890	3	400	14	13	435	382	Fine pearlite
Comp. Ex. 2-1	A	950	900	890	15	400	3	13	690	410	Partially martensite
Comp. Ex. 2-2	B	950	900	890	15	400	3	13	720	420	Partially martensite
Comp. Ex. 2-3	C	950	900	890	15	400	3	12	740	435	Partially martensite

[0092] In Examples 2, as the temperature-adjusted rolling, rolling in four passes in total containing three universal mills and one caliber rolling mill was performed so that the area reduction ratios of the head portion 91 and the foot portion 93 were 30%. The surface temperatures of the head portion 91 and the foot portion 93 in the temperature-adjusted rolling and the start temperature, the cooling rate, and the end temperature in the heat treatment were set as shown in the conditions shown in Table 3. When the heat treatment was performed, air was used for a cooling medium under the condition where the cooling rate was 3°C/s or less and a mixture of air and mist was used for a cooling medium under the condition where the cooling rate exceeded 3°C/s. The other manufacturing conditions were the same as those of Examples 1.

[0093] With respect to the total elongation of the rail 9, test pieces were collected, and then the total elongation was measured by the same method as that of Examples 1. With respect to the hardness of the rail 9, a sample 9c was collected from a position of the head portion surface illustrated in FIG. 6 and a sample 9d was collected from a position inside the head portion from the test pieces of about 20 mm thickness sawn from four places of an end portion, the 1/4 position, the 1/2 position, and the 3/4 position in the longitudinal direction of the rail 9. The sample 9c was collected from the center of the upper end surface of the head portion 91 of the test pieces polished in order to remove surface unevenness. The sample 9d was collected from a position at the center in the width direction and having a distance d4 = 20 mm from the upper end of the head portion 91 of the test pieces polished in order to remove surface unevenness . Next, the hardness of the collected samples 9c and 9d was measured by a Brinell hardness test. With respect to the surface structure, the surface structure of the collected samples 9c was observed.

[0094] In Examples 2, as examples different in the chemical composition, the surface temperature in the temperature-adjusted rolling, and conditions in the heat treatment, rails 9 were manufactured under 21 kinds of conditions of Examples 2-1 to 2-21, and then the total elongation and the hardness were measured and further the surface structure was observed. In Example 2-13, the heat treatment was not performed and the rail 9 after the hot-rolling was conveyed to the cooling bed 8, and then cooled until the temperature reached 100°C or less. After the rail 9 reached 100°C or less, the rail was straightened.

[0095] Also in Comparative Examples 2-1 to 2-3 in which the cooling rate in the heat treatment exceeded the ranges of the embodiment described above, rails 9 were manufactured as comparative examples under the same conditions as those of Examples 2-1 to 2-21, and then the total elongation and the hardness were measured and further the surface structure was observed as shown in Table 3. The values of the total elongation and the hardness shown in Table 3 show the average value of the four samples individually collected from the test pieces collected from the four places.

[0096] It was confirmed that, in Examples 2-1 to 2-21 in which the heat treatment was performed at a cooling rate of 0.5°C/s or more and 10°C/s or less, the total elongations of the head portion 91 and the foot portion 93 were 12% or more as the target total elongation in all the conditions.

[0097] In Examples 2-2 and 2-3, the surface temperature of the head portion 91 in the temperature-adjusted rolling was lower than that in other conditions, the surface temperature in starting the heat treatment was also low and the total elongation of the head portion 91 was 15% or more, which was higher than that in other conditions. However, in Examples 2-2 and 2-3, the hardness of the head portion 91 was 380 HB or less, which was lower than that in Example 2-1.

[0098] In Examples 2-1, 2-7 to 2-10, and 2-14 to 2-21 in which the conditions except the cooling rate in the heat treatment were the same and, further, in Examples 2-14 to 2-21 in which the composition is different, the hardness of the surface and inside of the head portion 91 improved when the cooling rate was higher. In Examples 2-1, 2-7 to 2-10, and 2-14 to 2-21 and Comparative Examples 2-1 to 2-3 in which the conditions except the cooling rate in the heat treatment were the same and, further, in Comparative Examples 2-1 to 2-3 in which the cooling rate exceeded 10°C/s, the cooling rate was excessively high, and therefore the structure was partially transformed into a martensite and the total elongation was as very low as 3%.

[0099] In Examples 2-1, 2-11, and 2-12 in which the conditions except the end temperature in the heat treatment were the same, the hardness of the surface and inside of the head portion 91 improved when the cooling stop temperature was lower. In Example 2-11 in which the end temperature in the heat treatment was set to 650°C, the pearlite structure was partially spheroidized.

[0100] In Example 2-13 in which the heat treatment was not performed, the total elongations of the head portion 91 and the foot portion 93 were 12% or more but the hardness of the surface and inside of the head portion 91 was the lowest in all the conditions. In Example 2-13, the pearlite structure was partially spheroidized.

[Example 3]

[0101] Next, Examples 3 performed by the present inventors are described.

[0102] In Examples 3, in order to confirm influences on the hardness and the surface structure by re-heat treatment, re-heating was performed before the heat treatment with respect to the condition of Example 2-3 in which the hardness was low. In Examples 3, manufacturing conditions other than the surface temperature of the head portion 91 in the temperature-adjusted rolling and performing re-heating were the same as those of Example 2-3. Table 4 individually shows the chemical composition, the surface temperature in the temperature-adjusted rolling, the conditions in the reheating and the heat treatment, the measurement results of the total elongation, the measurement results of the hardness, and the observation results of the head portion surface structure in Example 3. The total elongation values and the hardness shown in Table 4 show the average value of the four samples, i.e., the sum of one sample collected from each of the test pieces collected from each of the four places .

[Table 4]

Condition	Composition	In temperature-adjusted rolling		Re-heating		In heat treatment			Total elongation		Hardness		Head portion surface structure
		Head portion temperature [°C]	Foot portion temperature [°C]	Presence or absence	Position	Start temperature [°C]	Cooling rate [°C/s]	End temperature [°C]	Head portion [%]	Foot portion [%]	Head portion surface [HB]	Head portion inner region [HB]	
Ex. 3-1	A	650	900	Not performed		630	3	400	18	13	380	360	Coarse pearlite
Ex. 3-2	A	650	900	Performed	Entire	700	3	400	18	13	380	360	Coarse pearlite
Ex. 3-3	A	950	900	Performed	Entire	750	3	400	18	13	400	365	Fine pearlite
Ex. 3-4	A	950	900	Performed	Entire	890	3	400	18	13	410	380	Fine pearlite
Ex. 3-5	A	950	900	Performed	Entire	950	3	400	18	13	410	380	Fine pearlite
Ex. 3-6	A	650	900	Performed	Only head portion	700	3	400	18	13	380	360	Coarse pearlite
Ex. 3-7	A	950	900	Performed	Only head portion	750	3	400	18	13	400	365	Fine pearlite
Ex. 3-8	A	950	900	Performed	Only head portion	890	3	400	18	13	410	380	Fine pearlite
Ex. 3-9	A	950	900	Performed	Only head portion	950	3	400	18	13	410	380	Fine pearlite

[0103] In Examples 3, the head portion 91 or the entire rail 9 was re-heated with the re-heating device 6 after the hot-rolling. The re-heating device 6 is an induction heating type heating device and is able to heat the head portion 91 or the entire rail 9 according to the conditions shown in Table 4. The surface temperature of the head portion 91 after the re-heating is the start temperature in the heat treatment shown in Table 4.

[0104] In Examples 3, rails 9 were manufactured under 9 kinds of conditions of Examples 3-1 to 3-9 different in the surface temperature of the head portion 91 in the temperature-adjusted rolling and the re-heating conditions, and then the total elongation and the hardness were measured and further the surface structure was observed. A method for collecting samples for the total elongation and the hardness and a method for collecting samples for observing the surface structure are the same as those of Examples 2. Example 3-1 is the condition in which the re-heating was not performed and has the same manufacturing conditions as those of Example 2-3.

[0105] As shown in Table 4, it was confirmed that, in all the conditions of Examples 3-1 to 3-9, the total elongations of the head portion 91 and the foot portion 93 were 12% or more as the target total elongation.

[0106] In Example 3-1 in which the re-heating was not performed, the surface temperature in starting the temperature-adjusted rolling was low, and therefore the surface temperature of the head portion 91 in starting the heat treatment was as low as 630°C and the hardness of the surface and inside of the head portion 91 was low.

[0107] In Examples 3-2 and 3-6, the re-heating was performed and the surface temperature of the head portion 91 in starting the heat treatment was set to 700°C but the surface temperature was as low as 730°C or less, and therefore the hardness of the surface and inside of the head portion 91 was low as in Example 3-1.

[0108] It was confirmed that, in Examples 3-3 to 3-5 in which the entire rail 9 was re-heated and Examples 3-7 to 3-9 in which only the head portion 91 was re-heated, the hardness improved by 20 HB or more on the surface of the head portion 91 and 5 HB or more inside the head portion 91 as compared with Examples 3-2 and 3-6 in which the temperature after the re-heating was low. Moreover, it was confirmed that there is no difference in the hardness improvement effect of the head portion 91 between the case where the entire rail 9 was re-heated and the case where only the head portion 91 was re-heated. Furthermore, it was confirmed that there is no difference in the hardness of the head portion 91 when Examples 3-4, 3-5, 3-8, and 3-9 are compared, and therefore there is no difference in the hardness improvement effect by re-heating when the surface temperature after the re-heating was 900°C or more.

[0109] It was confirmed from the results described above that the rail 9 having high ductility in both the head portion 91 and the foot portion 93 is able to be manufactured according to the method for manufacturing a rail according to the present invention.

Reference Signs List

[0110]

1:	manufacturing apparatus
2:	heating furnace
3A, 3A1 to 3An:	roughing mill
3B:	finishing mill
4:	rough cooling device
41:	head portion cooling nozzle
42:	foot portion cooling nozzle
43 :	head portion thermometer
44 :	foot portion thermometer
45:	conveyance table
46a, 46b:	guide
461a, 461b:	opening
5:	finish cooling device
6:	re-heating device
7:	heat treatment apparatus
71a to 71c:	head portion cooling header
72:	foot portion cooling header
73:	head portion thermometer
74:	control unit
8:	cooling bed
9:	rail
91:	head portion
92:	web portion
93:	foot portion

Claims

1. A rail manufacturing method comprising:

   hot-rolling a heated steel rail material by at least one first rolling mill (3A1...3AK) ; and
   adjusting a temperature by cooling the hot-rolled steel rail material;
   characterized in that: the method further comprises:

   rolling the steel rail material subjected to the temperature adjustment into a rail shape at the adjusted temperature, and at an area reduction ratio of 20% or more by at least one second rolling mill (3AK+1...3AN, 3B);
   in the adjusting a temperature of the steel rail material, a surface portions of the steel rail material corresponding to a head portion (91) and a foot portion (93) of the rail shape are cooled so that the temperatures of the surface portions reach 500°C or more and 1,000°C or less by a cooling device (4) arranged between the at least one first rolling mill (3A1...3AK) and the at least one second rolling mill (3AK+1...3AN, 3B); and
   after the rolling, heat-treating the rail (9) by forcibly cooling at an average cooling rate of 1°C/s or more and 10°C/s or less from a surface temperature of 730°C or more until the surface temperature reaches 600°C or less,
   wherein the steel material has a composition comprising 0.60% or more and 1.05% or less carbon (C), 0.1% or more and 1.5% or less silicon (Si), 0.01% or more and 1.5% or less manganese (Mn), 0.035% or less phosphorus (P), 0.030% or less sulfur (S), 0.1% or more and 2.0% or less chromium (Cr), 0.5% or less antimony (Sb), optionally at least one of: 0.01% or more and 1.0% or less copper (Cu); 0.01% or more and 0.5% or less nickel (Ni); 0.01% or more and 0.5% or less molybdenum (Mo); 0.001% or more and 0.15% or less vanadium (V); 0.001% or more and 0.030% or less niobium (Nb), and the balance being iron (Fe) and inevitable impurities.

2. The rail manufacturing method according to Claim 1 comprising:
   before the heat-treating the rail (9), re-heating the rail (9) to 730°C or more when the surface temperature of the head portion (91) of the rail (9) is 730°C or less.

3. The rail manufacturing method according to Claim 2, wherein,
   in the re-heating the rail (9), only the head portion (91) of the rail (9) is reheated.

Patentansprüche

1. Verfahren zur Herstellung von Schienen, umfassend:

   Warmwalzen eines Schienenmaterials aus erhitztem Stahl durch mindestens eine erste Walzanlage (3A1...3AK); und
   Anpassen einer Temperatur durch Kühlen des warmgewalzten Schienenmaterials aus Stahl;
   dadurch gekennzeichnet, dass: das Verfahren weiter umfasst:

   Walzen des Schienenmaterials aus Stahl, das der Temperaturanpassung unterzogen wird, in eine Schienenform bei der angepassten Temperatur und bei einem Bereichsverringerungsverhältnis von 20 % oder mehr durch mindestens eine zweite Walzanlage (3AK+1...3AN, 3B);
   wobei, bei dem Anpassen einer Temperatur des Schienenmaterials aus Stahl, ein Oberflächenabschnitte des Schienenmaterials aus Stahl entsprechend einem Kopfabschnitt (91) und einem Fußabschnitt (93) der Schienenform durch eine Kühlvorrichtung (4), die zwischen der mindestens einen ersten Walzanlage (3A1...3AK) und der mindestens einen zweiten Walzanlage (3AK+1...3AN, 3B) angeordnet ist, gekühlt werden, sodass die Temperaturen der Oberflächenabschnitte 500 °C oder mehr und 1.000 °C oder weniger erreichen; und
   nach dem Walzen, Wärmebehandeln der Schiene (9) durch Zwangskühlen bei einer Durchschnittskühlrate von 1°C/s oder mehr und 10°C/s oder weniger von einer Oberflächentemperatur von 730 °C oder mehr, bis die Oberflächentemperatur 600 °C oder weniger erreicht,
   wobei das Stahlmaterial eine Zusammensetzung aufweist, umfassend 0,60 % oder mehr und 1,05 % oder weniger Kohlenstoff (C), 0,1 % oder mehr und 1,5 % oder weniger Silizium (Si), 0,01 % oder mehr und 1,5 % oder weniger Mangan (Mn), 0,035 % oder weniger Phosphor (P), 0,030 % oder weniger Schwefel (S),

0,1 % oder mehr und 2,0 % oder weniger Chrom (Cr), 0,5 % oder weniger Antimon (Sb), optional mindestens eines von: 0,01 % oder mehr und 1,0 % oder weniger Kupfer (Cu); 0,01 % oder mehr und 0,5 % oder weniger Nickel (Ni); 0,01% oder mehr und 0,5 % oder weniger Molybdän (Mo); 0,001 % oder mehr und 0,15% oder weniger Vanadium (V); 0,001 % oder mehr und 0,030 % oder weniger Niob (Nb), und wobei der Rest Eisen (Fe) und unvermeidliche Verunreinigungen sind.

2. Verfahren zur Herstellung von Schienen nach Anspruch 1, umfassend:
vor dem Wärmebehandeln der Schiene (9), Wiedererwärmen der Schiene (9) auf 730 °C oder mehr, wenn die Oberflächentemperatur des Kopfabschnitts (91) der Schiene (9) 730 °C oder weniger ist.

3. Verfahren zur Herstellung von Schienen nach Anspruch 2, wobei,
bei dem Wiedererwärmen der Schiene (9), nur der Kopfabschnitt (91) der Schiene (9) wiedererwärmt wird.

Revendications

1. Procédé de fabrication de rail comprenant :

le laminage à chaud d'un matériau de rail en acier chauffé par au moins un premier laminoir (3A1 ... 3AK) ; et l'ajustement d'une température par refroidissement du matériau de rail en acier laminé à chaud ;
caractérisé en ce que : le procédé comprend en outre :

le laminage du matériau de rail en acier soumis à l'ajustement de température en une forme de rail à la température ajustée, et à un rapport de réduction de section de 20 % ou plus par au moins un second laminoir (3AK+1 ... 3AN, 3B) ;
dans l'ajustement d'une température du matériau de rail en acier, des portions de surface du matériau de rail en acier correspondant à une portion de tête (91) et à une portion de pied (93) de la forme de rail sont refroidies de sorte que les températures des portions de surface atteignent 500 °C ou plus et 1000 °C ou moins par un dispositif de refroidissement (4) agencé entre l'au moins un premier laminoir (3A1 ... 3AK) et l'au moins un second laminoir (3AK+1 ... 3AN, 3B) ; et
après le laminage, le traitement thermique du rail (9) par refroidissement forcé à une vitesse de refroidissement moyenne de 1 °C/s ou plus et 10 °C/s ou moins à partir d'une température de surface de 730 °C ou plus jusqu'à ce que la température de surface atteigne 600 °C ou moins,
dans lequel le matériau d'acier a une composition comprenant 0,60 % ou plus et 1,05 % ou moins de carbone (C), 0,1% ou plus et 1,5 % ou moins de silicium (Si), 0,01% ou plus et 1,5 % ou moins de manganèse (Mn), 0,035 % ou moins de phosphore (P), 0,030 % ou moins de soufre (S), 0,1 % ou plus et 2,0 % ou moins de chrome (Cr), 0,5 % ou moins d'antimoine (Sb), éventuellement au moins l'un de : 0,1 % ou plus et 1,0 % ou moins de cuivre (Cu) ; 0,01 % ou plus et 0,5 % ou moins de nickel (Ni) ; 0,01 % ou plus et 0,5 % ou moins de molybdène (Mo); 0,001 % ou plus et 0,15 % ou moins de vanadium (V) ; 0,001 % ou plus et 0,030 % ou moins de niobium (Nb), et le reste étant constitué de fer (Fe) et d'impuretés inévitables.

2. Procédé de fabrication de rail selon la revendication 1, comprenant :
avant le traitement thermique du rail (9), le réchauffage du rail (9) jusqu'à 730 °C ou plus lorsque la température de surface de la portion de tête (91) du rail (9) est de 730 °C ou moins.

3. Procédé de fabrication de rail selon la revendication 2, dans lequel,
dans le réchauffage du rail (9), seule la portion de tête (91) du rail (9) est réchauffée.

FIG. 1

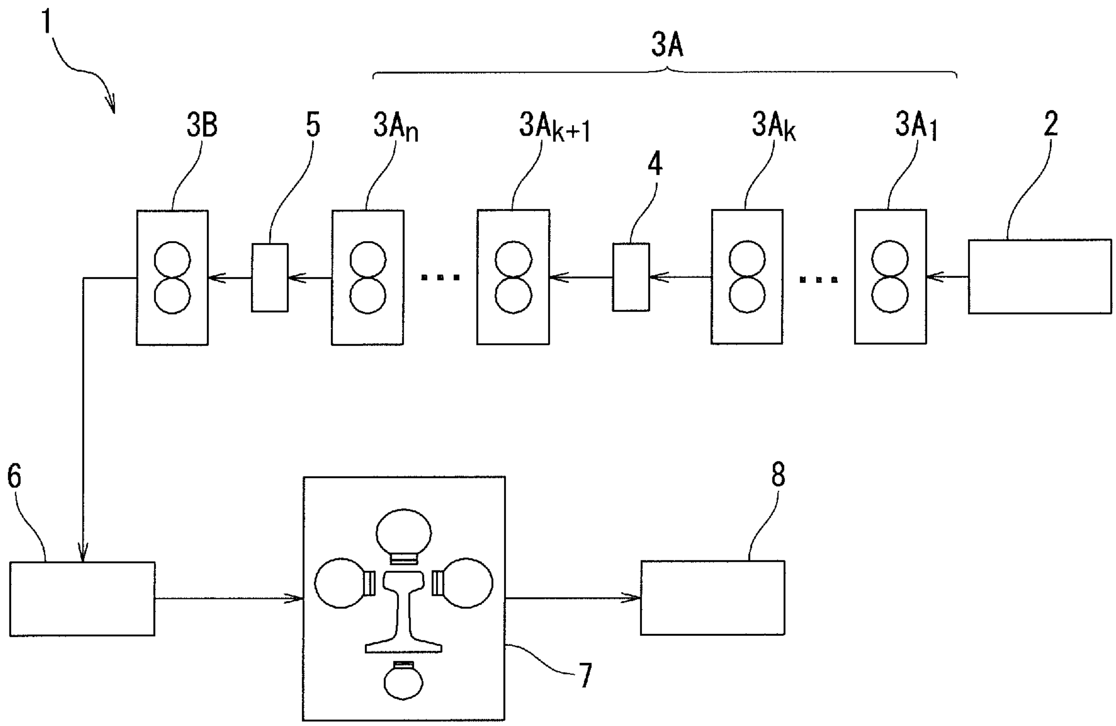

1
3A
3B
5
3An
3Ak+1
4
3Ak
3A1
2
6
8
7

FIG. 2

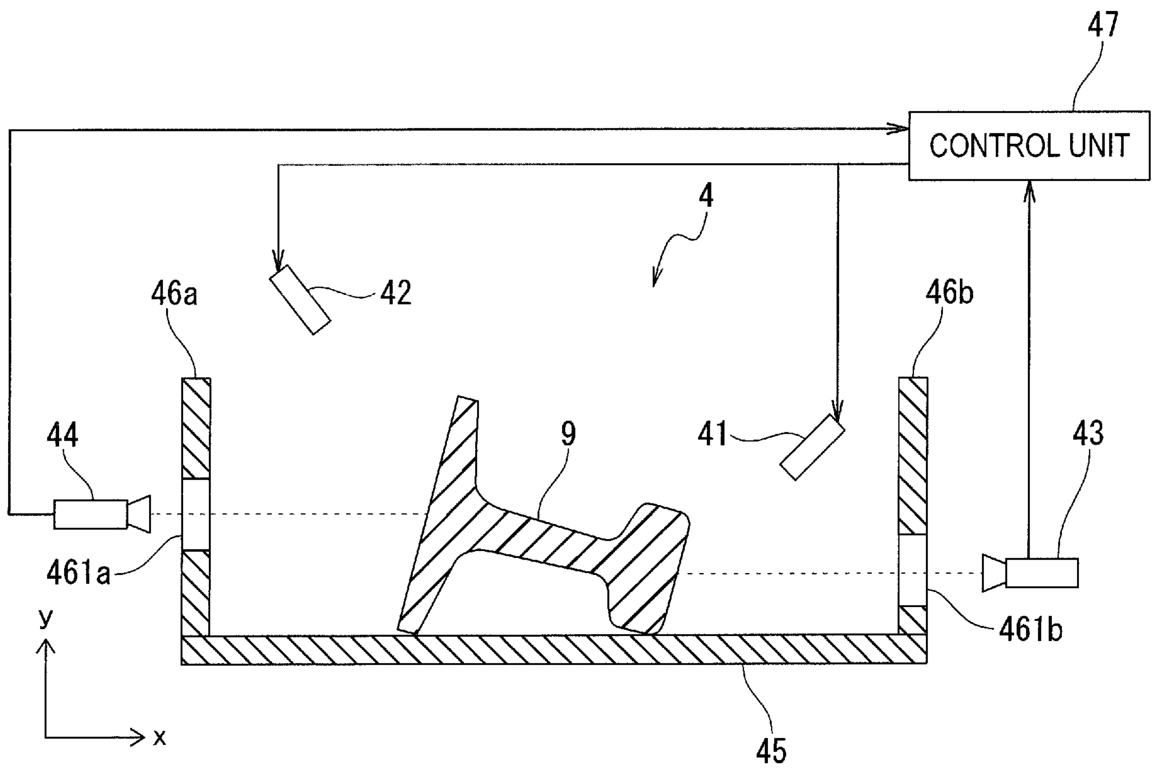

47
CONTROL UNIT
4
46a
42
46b
44
9
41
43
461a
461b
y
x
45

FIG. 3

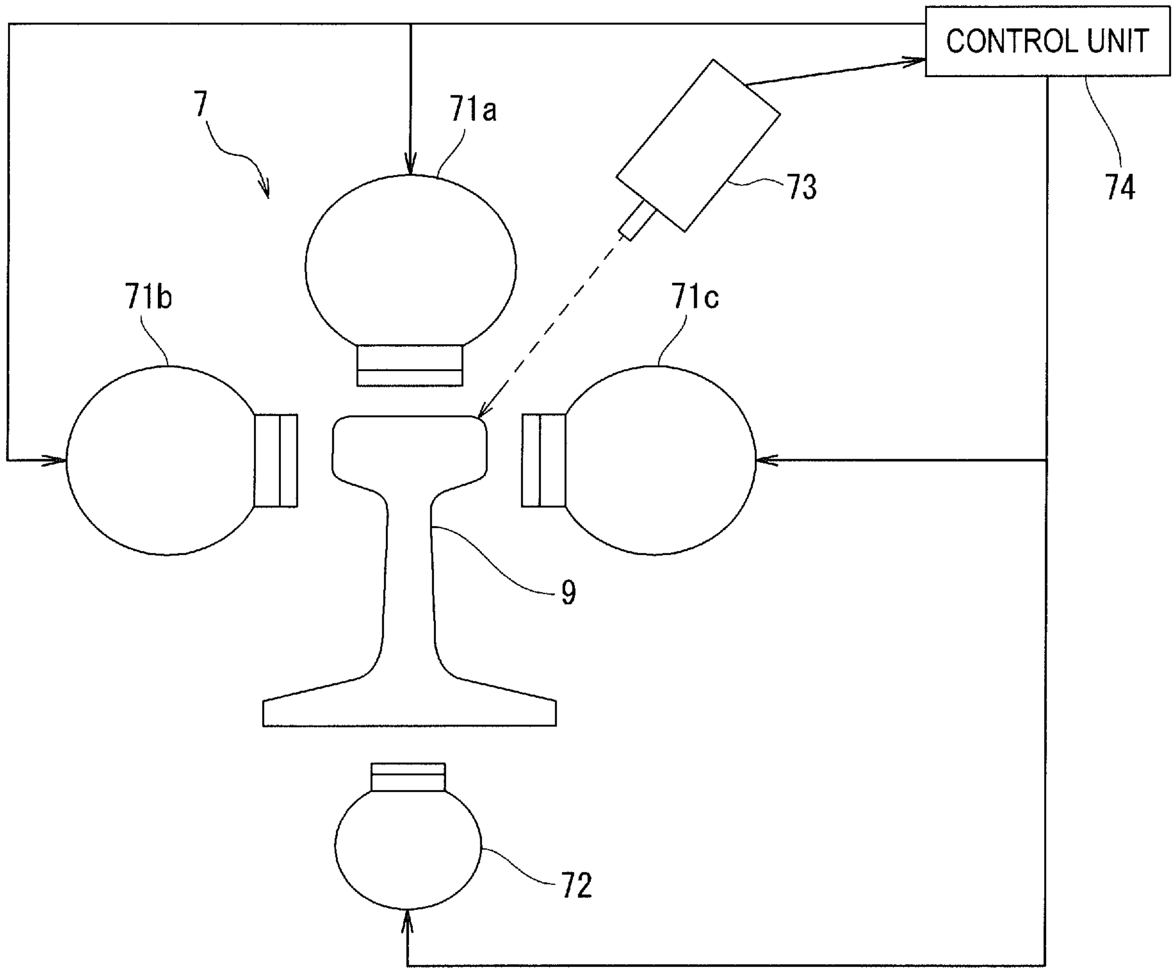


FIG. 4

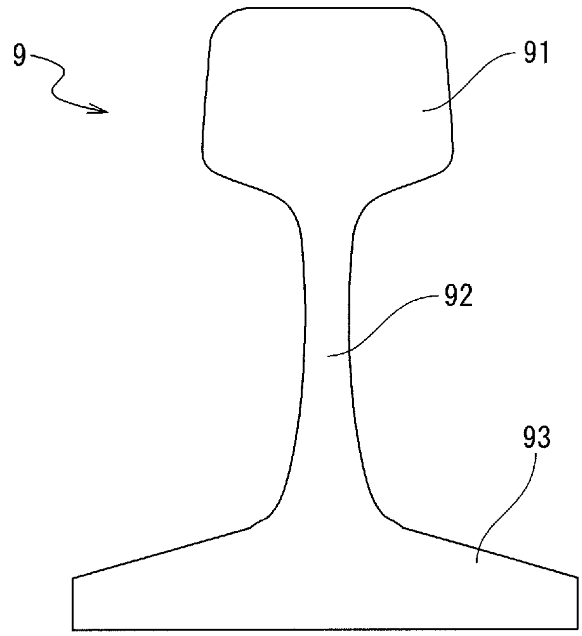


FIG. 5

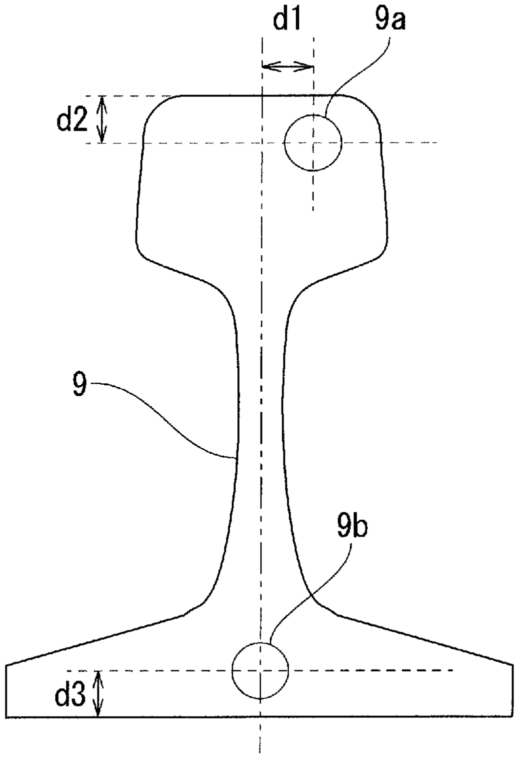
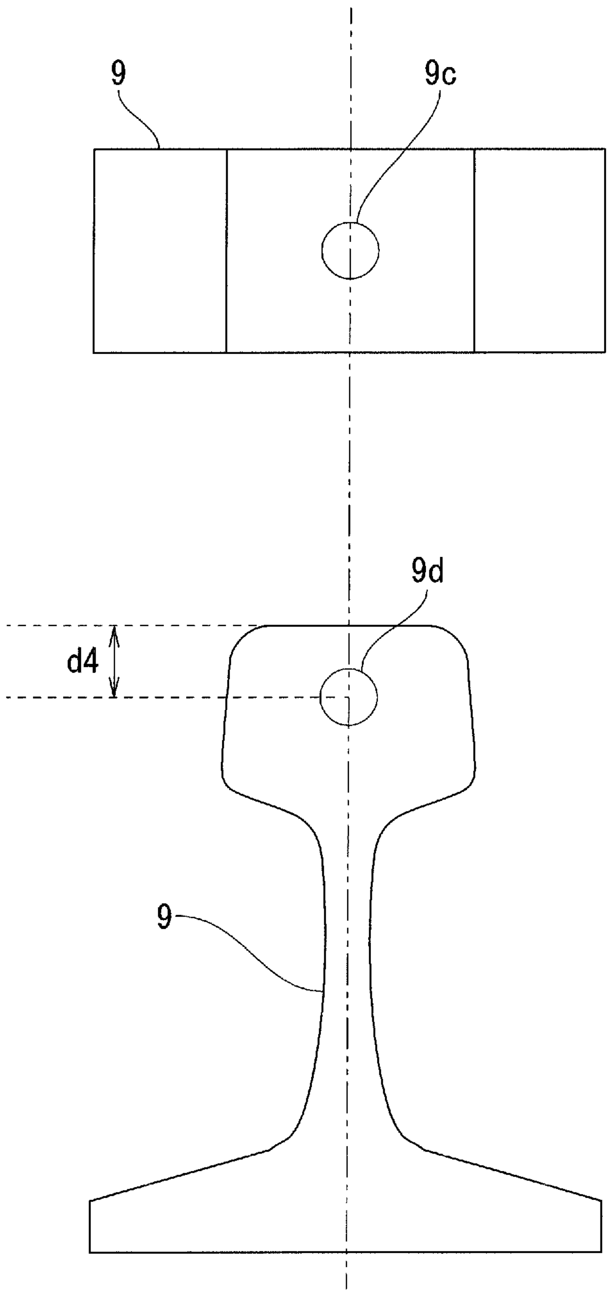


FIG. 6



REFERENCES CITED IN THE DESCRIPTION

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