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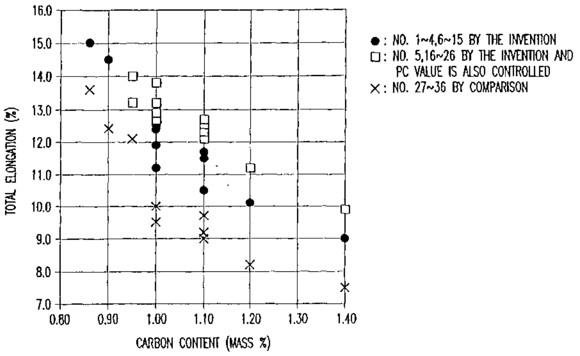
(54) A method for producing high-carbon steel rails excellent in wear resistance and ductility

(57) Disclosed are 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: $S \leqq 800 / (C \times T)$, 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: $S \leqq 2400 / (C \times T \times P)$, 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.



RELATIONSHIP BETWEEN THE CARBON CONTENT AND THE TOTAL ELONGATION VALUE OF THE RAIL

FIG.7

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Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] This invention relates to methods for producing pearlitic steel rails having a high content of carbon. The present steel rails are excellent in both wear resistance and ductility and may be used in railroads for carrying heavy loads.

Description of the Related Art

[0002] Pearlitic steel having a high carbon content has been used for railroads due to its excellent wear resistance. However, the high carbon content therein also causes problems of low ductility and toughness. For example, steel rails having a typical carbon content (e.g., containing about 0.6 - 0.7 mass% of carbon described in JIS (Japan Industrial Standard) E1101-1990) have a value according to the JIS No.3 U notch Charpy test at room temperature of around 12 - 18 J/cm^2. These steel rails having such typical carbon content have the problem of brittle fractures caused by small initial defects and fatigue cracks when used in lower temperature such as what we call it "cold range". In recent years, the carbon content of steel rails has increased in order to improve the wear resistance, which causes further lowering of both the ductility and the toughness of the steel rails.

[0003] Generally, it is said that grain refinement of the pearlite structure, more specifically having a fine-grained structure of both austenite (before transformation to pearlite) and pearlite, is effective in simultaneously improving both ductility and toughness of the steel rail. In order to obtain a fine-grained structure of austenite, a decrease in the temperature and an increase in the amount of the reduction rate of the hot rolling process are carried out. Furthermore, a reheat treatment at a low temperature after rolling is carried out. In order to obtain a fine-grained structure of pearlite, an acceleration of pearlite transformation from austenite grains by the use of seed transformation is carried out.

[0004] However, decreasing the temperature and increasing the amount of the reduction rate of the hot rolling process have a limitation in terms of maintaining good formability. This limitation has not allowed production of a sufficiently fine-grained austenite grain. As for effecting pearlite transformation from austenite grain using seed transformation, it is difficult to control the amount of seed transformation. This limitation makes it difficult to perform stable pearlite transformation from austenite grain.

[0005] In view of above, the following method has been used. This method is one where a fine-grained pearlite structure is obtained by pearlite transformation caused by rapid cooling after reheat treatment of a steel rail at a low temperature following a rolling process. This method improves both the ductility and the toughness of the pearlitic steel rail. However, the carbon rails, in which has increased the carbon content in order to improve the wear resistance, causes a decrease in the ductility and toughness of the pearlite structure after the accelerated cooling process. This problem is due to the fact that coarse carbides remain insoluble in the austenite grains when the reheat treatment at a low temperature is carried out. The reheat process also introduces economic problems since it generally increases the production cost and decreases the productivity.

[0006] Research and development of a production method for steel rails having a high carbon rails, which simultaneously ensures both formability during rolling and a fine-grained pearlite structure after rolling has been required. In order to address this requirement, the following production methods of high-carbon steel rails have been developed:

(1) Japanese Laid-open Patent Hei 07-173530 discloses a production method for steel rails with high ductility where three or more consecutive passes of rolling at set intervals of time from one pass to next pass is carried out in the finish rolling process of high carbon content steel rails;
(2) Japanese Laid-open Patent Hei 2001-234238 discloses a production method for steel rails with a high wear resistance and a high toughness where two or more consecutive passes of rolling at set intervals of time from one pass to the next pass is performed, then continuous rolling and rapid cooling are sequentially carried out in the finish rolling process of high carbon content steel rails; and
(3) Japanese Laid-open Patent Hei 2002-226915 discloses a production method for steel rails with a high wear resistance and a high toughness where cooling is allowed between passes of rolling (inter-stand), and continuous rolling and rapid cooling are sequentially carried out in the finish rolling process of high-carbon rails.

[0007] Features of the rails in the above Japanese Laid-open Patent Hei 07-173530, 2001-234238, and 2002-226915 include improved ductility and toughness of pearlitic steel by obtaining a uniformly sized fine-grained austenite grain by continuous rolling thereby achieving a small reduction. This takes advantage of the fact that steel with high carbon content is easy to recrystallize at relatively low temperatures and with only a small reduction.

[0008] The continuous rolling methods mentioned above, which are mainly combinations of the carbon content of steel, the temperature of continuous hot rolling, the number of rolling passes and the time between passes, cannot achieve a fine-grain austenite structure. This leads to a coarse pearlite structure and results in a failure to improve ductility. This is especially true for the method employing cooling between passes of rolling (inter-stand), as the rate of grain growth immediately after rolling is high in high carbon content steel. Thus, the grain growth depends remarkably on the interval of time if cooling is carried out between rollings (inter-stand) Therefore, a fine-grained austenite structure is not obtained and the pearlite structure becomes coarse. This results in the problem of no improvement of ductility, even if the above-mentioned methods of continuous rolling and/or cooling between rollings (inter-stand) are applied.

SUMMARY OF THE INVENTION

[0009] An object of the present invention is to provide a method for manufacturing a rail that is excellent in both ductility and wear resistance by producing a pearlite of fine-grain structure and high hardness.

[0010] One embodiment of the invention relates to a method for 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 for a cross-section of the rail of 2-30%, wherein conditions of the finish rolling satisfy the following relationship: $S \leqq CPT1$; wherein the CPT1 is the value expressed by the following expression 1

$$CPT1 = 800 / (C \times T) \qquad \text{(expression 1)}$$

wherein S is the maximum rolling interval time (seconds), and $(C \times T)$ is defined as follows; C is the carbon content of the steel, wherein the carbon content is more than 0.85 mass%, but less than or equal to 1.40 mass%, based on the total mass of the steel, and T is the maximum surface temperature (degree C) of a rail head. This method produces a steel rail with a high content of carbon that is excellent in wear resistance and ductility.

[0011] Another embodiment of the invention relates to a method for 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 for a cross-section of the rail of 2-30%, wherein conditions of the finish rolling satisfy the following relationship: $S \leqq CPT2$, wherein the CPT2 is the value expressed by the following expression 2,

$$CPT2 = 2400 / (C \times T \times P) \qquad \text{(expression 2)}$$

wherein S is the maximum rolling interval time (seconds), and $(C \times T \times P)$ is defined as follows; C is the carbon content of the steel rail, wherein the carbon content is more than 0.85 mass%, but less than or equal to 1.40 mass%, based on the total mass of the steel, and T is the maximum surface temperature (degree C) of a rail head, and P is the number of passes, which is 3 or more. This method produces a steel rail with a high content of carbon that is excellent in wear resistance and ductility.

[0012] In yet another embodiment, the rail of the present invention, in addition to the carbon, further comprises at least one element in the following list: Si, Mn, Cr, Mo, B, Co, Cu, Ni, Ti, Mg, Ca, Al, Zr, N, V, Nb. The balance of the rail comprises Fe. Additionally, the rail further optionally comprises impurities, which may be unavoidable.

[0013] In another embodiment, the chemical composition of the rail meet the following expression: $0.30 \geqq PC \geqq 0.04$; where PC is expressed as the following (expression 3),

$$PC = V(\text{mass\%}) + 10 \times Nb(\text{mass\%}) + 5 \times N(\text{mass \%}) \qquad \text{(expression 3)}$$

[0014] In yet another embodiment, the methods of the present invention further comprise: immediately after finish rolling, cooling the surface of the rail head at a cooling rate of 2-30°C/second until the surface temperature reaches 950-750°C. Optionally, after such cooling, when the temperature of the rail head is more than 700°C, the methods further comprise cooling the surface of the rail head at a cooling rate of 2-30°C/second until the surface temperature reaches at least 600°C, and then allowing the rail to further cool at room temperature (e.g., approximately 45°F to 95°F, preferably 65°F to 85°F).

[0015] In another embodiment, the methods of the present invention further comprise: after the finish rolling process, when the temperature of the rail head is more than 700°C, cooling the surface of the rail head at a cooling rate of 2-30°C/

second until the surface temperature reaches at least 600°C, and then allowing the rail to further cool at room temperature (e.g., approximately 45°F to 95°F, preferably 65°F to 85°F).

[0016] According to the present invention, it is possible with respect to a rail to obtain a fine-grained pearlite structure with high-hardness, to improve the ductility of the rail and to increase the life-span of the rail. This is a result of applying one or more of the following conditions when a high carbon content bloom of rail is continuously finish-rolled to form a rail:

(1) The maximum interval time of rolling is controlled to be less than the time calculated from an expression concerning the carbon content of steel and the maximum surface temperature of rail at rolling (rail head) or from an expression concerning the carbon content of steel and the maximum surface temperature of rail at rolling (rail head) and the number of passes,
(2) The additional amounts of V, Nb and N are controlled so as to be within a range defined based from an expression concerning each additional amount of V, Nb and N in order to inhibit the growth of austenite grain caused after the continuous rolling,
(3) Immediately after the continuous rolling, the surface of the head of the rail is rapidly cooled down at a predetermined cooling rate in a predetermined temperature range, and
(4) Furthermore the surface of the head of the rail in an austenite phase is rapidly cooled down at a predetermined cooling rate in a predetermined temperature range to obtain a pearlite structure excellent in wear resistance and ductility.

BRIEF DESCRIPTION OF DRAWINGS

[0017] FIG.1: Shows the relationship between the maximum temperature of the rail head (°C) and the multiple of S, C, T (S× C×T), where S is the maximum interval time of rolling (seconds), C is the carbon content of the steel (mass%), and T is the maximum temperature of rail head (°C).

[0018] FIG.2: Shows the relationship between the carbon content (mass%) and the multiple of S, C, T (S × C × T), where S is the maximum interval time of rolling (seconds), C is the carbon content of the steel (mass%), and T is the maximum temperature of the rail head (°C).

[0019] FIG.3: Shows the relationship between the maximum interval time of rolling (second) and the multiple of S, C, T (S×C×T), where S is the maximum interval time of rolling (seconds), C is the carbon content of the steel, and T is the maximum temperature of the rail head (°C).

[0020] FIG.4: Shows the relationship between the number of rollings (times) and the multiple of S, C, T, P (S×C×T×P), where S is the maximum interval time of rolling (seconds), C is the carbon content of the steel (mass%), T is the maximum temperature of the rail head (°C), and P is the numbers of rollings (times).

[0021] FIG.5: An illustration explaining the different portions of the rail. In FIG.5, **1** is the top of rail head, and **2** is the head corner.

[0022] FIG.6: Shows the portion of the rail where the specimen for the tensile test is taken.

[0023] FIG.7: Shows the relationship between the carbon content and the total elongation value of the rail. In FIG.7,
• indicates a rail produced by the methods of the invention without control of the expression:

$$0.30 \geqq V(\text{mass\%}) + 10\times Nb(\text{mass\%}) + 5\times N(\text{mass \%}) \geqq 0.04,$$

☐ indicates a rail produced by the methods of the invention with the control of the above expression (PC value, wherein

$$PC = V(\text{mass\%}) + 10\times Nb(\text{mass\%}) + 5\times N(\text{mass \%}),$$

therefore,
0.30 ≧ PC ≧ 0.04), and
x indicates a rail produced by conventional methods.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0024] The present inventors analyzed factors that cause the pearlite structure to be coarse, which is the reason why ductility is not improved. This analysis was performed by studying the combinations of carbon content, the surface temperature at the rail head, the reduction rate of the cross-section of the rail, and the interval time of rolling. After various experiments, it was found that the grain size of austenite structure turns coarse after continuous hot rolling if the maximum interval time during continuous rolling exceeds a certain value.

[0025] The present inventors investigated why the grain size of austenite become coarse if the maximum interval time of rolling increases. It was found that the growth of grains of austenite structure have a positive correlation with the carbon content of the steel and the maximum surface temperature of the rail head during continuous finish rolling. In addition, it was also found that there is a positive correlation between the growth of grains of austenite structure and the number of passes of rolling, such as when the number of passes of rolling is 3 or more.

[0026] Based on the above results, the present inventors carried out an analysis of multiple correlations on the relationship between the optimal interval time of rolling for inhibiting the grain size of austenite from becoming coarse, the carbon content, the maximum surface temperature of the rail head during continuous finish-rolling, and the number of rolling passes. The result was that the growth of austenite grain at the interval of rolling is inhibited and a fine-grained austenite structure is obtained if the maximum interval time of continuous rolling is equal to or less than the value calculated by particular equations. If the number of rolling passes is 2, the equation is one based on the carbon content and the maximum surface temperature of the rail head. However, if the number of rolling passes is 3 or more, the equation is one based on the carbon content, the maximum surface temperature of the rail head, and the number of passes of rolling.

[0027] The present inventors also investigated a method for inhibiting the growth of austenite grain caused after continuous rolling by controlling precipitation. It was found that the precipitation of V-carbide, V-Nitride, V-carbonitride, Nb-carbide and Nb-carbonitride generated during continuous rolling causes pinning of austenite grains, which inhibits the growth of austenite grain. In addition, the present inventors investigated the conditions where the precipitation of V-carbide, V-Nitride, V-carbonitride, Nb-carbide and Nb-carbonitride during the continuous rolling can be fully controlled. The result is that the growth of austenite grain after continuous rolling is inhibited enough if the amount of addition of V, Nb and N (mass%) are controlled, respectively, so that the value calculated by an equation based on the amount of addition of V, Nb and N (mass%) can be within a given range.

[0028] The present inventors further investigated a method of inhibiting the growth of austenite grain after (finishing) continuous rolling by applying rapid cooling immediately after the rolling. The result is that the growth of austenite grain after rolling can be inhibited if the surface of the rail head is cooled down rapidly within a predetermined range of temperature and at a predetermined cooling rate immediately after completing the continuos rolling.

[0029] In addition to the above, the present inventors further investigated a method of obtaining pearlite structure excellent in wear resistance and ductility from a fine-grained austenite structure. The result was that a pearlite structure having high toughness and fine-grained structure can be obtained by rapidly cooling the surface of the rail head having an austenite phase at a predetermined temperature range and at a predetermined cooling rate. The obtained pearlite structure of the rail head retains wear resistance and ductility.

[0030] The following are explanations of various limitations defining the present invention:

(1) The reason for the limitation on the chemical composition of steel rails: C (carbon) is an element for expediting pearlite transformation and ensuring wear resistance. If the C content is 0.85 mass% or less, it is difficult to ensure a volume ratio of cementite in the pearlite structure, which makes it difficult to ensure wear resistance in use for railroads carrying heavy loads. On the other hand, if the C content exceeds 1.40 mass%, a large amount of pro-eutectoid cementite is generated on the old austenite grain boundary, which lowers the wear resistance and the ductility. In view of this, the C content is limited to the range from more than 0.85 to 1.40 mass%. Preferably, a lower limit of C content of 0.95 mass% can highly improve the wear resistance, which greatly improves the life-span of the rail.

[0031] With respect to a rail produced using the above-mentioned composition, at least one of Si, Mn, Cr, Mo, B, Co, Cu, Ni, Ti, Mg, Ca, Al, Zr, N, V and/or Nb can be further added when needed for improving the hardness (strength) of the pearlite structure, for improving ductility of the pearlite structure, for preventing a heat affected zone, for instance a welding zone, from softening, and for controlling the section hardness distribution inside the rail head.

[0032] The reasons for the limitations by these elements are as follows: Si is an important element as an oxygen scavenger and as an element for increasing the hardness (strength) of the rail head through solid-solution strengthening with a ferrite phase in the pearlite structure. Besides, Si is an element for inhibiting generation of a pro-eutectoid cementite structure in a hyper-eutectoid steel to prevent the lowering of ductility. If the Si content is less than 0.05 mass%, these good effects cannot be significantly expected, and if the Si content is more than 2.00 mass%, the weldability is degraded because of generation of oxide and/or generation of a great deal of surface flaws during hot rolling. In addition, the hardenability is drastically increased and a martensite structure is generated which is detrimental to the wear resistance and the ductility of the rail. Thus, the Si content is limited to the range of from 0.05 to 2.00 mass%.

[0033] Mn is an element for increasing the hardenability and for improving the wear resistance by decreasing the pearlite lamellar spacing to ensure the hardness of the pearlite structure. If the Mn content is less than 0.05 mass%, these effects cannot be significantly expected, which makes it difficult to ensure the wear resistance necessary for the rail. If the Mn content is more than 2.00%, the hardenability is drastically increased and a martensite structure is generated which is detrimental to the wear resistance and the ductility of the rail. Therefore, the Mn content is limited to the range of from 0.05 to 2.00 mass%.

[0034] Cr is an element capable of increasing the equilibrium transformation temperature, which leads to decrease of the pearlite lamellar spacing to provide high hardness (strength). Cr is also capable of strengthening the cementite phase, which leads to increased hardness (strength) of the pearlite to provide improved wear resistance. If the Cr content is less than 0.05 mass%, these effects cannot be significantly expected. If the Cr content is more than 2.00%, the hardenability is drastically increased and a martensite structure is largely generated which degrades the wear resistance and the ductility of the rail. Therefore, the Cr content is limited to the range of from 0.05 to 2.00 mass %.

[0035] Mo is an element capable of increasing the equilibrium transformation temperature similar to Cr, which leads to decrease of the pearlite lamellar spacing to provide high hardness (strength). If the Mo content is less than 0.01 mass%, these effects cannot be expected, i.e. improvement of hardness of the rail cannot be significantly expected. If the Mo content is more than 0.50 mass%, the transformation rate is drastically lowered, which leads to generation of a martensite structure, which is detrimental to the ductility. In view of this, the Mo amount is limited to the range of from 0.01 to 0.50 mass%.

[0036] B (boron) is an element for forming iron-carbon boride on the grain boundary of austenite, increasing the fineness of the generated pro-eutectoid cementite structure, making the pearlite transformation temperature less dependent on the cooling rate and making hardness distribution of the rail head uniform, which prevents degradation of rail ductility and provides a longer life. If the B content is less than 0.0001 mass%, these effects cannot be significantly expected, i.e. there cannot be expected improvement with respect to generation of pro-eutectoid cementite structure and/or rail head hardness distribution uniformity. If the B content is more than 0.0050 mass%, coarse iron-carbon boride is generated on the austenite grain boundary, which greatly lowers the rail ductility and the fatigue-damage resistance. Thus, the B content is limited to the range of from 0.0001 to 0.0050 mass%.

[0037] Co is an element for making solid-solution with ferrite in the pearlite structure, which improves the hardness (strength) of the pearlite structure by solid-solution strengthening. Co is also an element for increasing the transformation energy of pearlite, which improves the ductility by refining the grain of the pearlite structure. Also, Co is an element for improving wear resistance by refining the grain of ferrite which is formed by wheel contact on the rail head. If the Co content is less than 0.003 mass%, these effects cannot be significantly expected. If the Co content is more than 2.00 mass%, the ductility of the ferrite phase in the pearlite structure is drastically lowered, which causes spalling damage on the rolling contact surface and lowers the surface damage resistance of the rail. Therefore, the Co content is limited to the range of from 0.003 to 2.00 mass%.

[0038] Cu is an element for making solid-solution with ferrite in the pearlite structure, which improves the hardness (strength) of the pearlite structure by solid-solution strengthening. If the Cu content is less than 0.01 mass%, these effects cannot be readily expected. If the Cu content is more than 1.00 mass%, the hardenability is drastically increased and a martensite structure is generated which is detrimental to the wear resistance of the rail. Further, the ductility of the ferrite phase in the pearlite structure is drastically lowered, which degrades the ductility of the rail. Therefore, the Cu content is limited to the range from 0.01 to 1.00 mass %.

[0039] Ni is an element for preventing the creation of brittleness during hot rolling caused by adding Cu and for increasing the hardness (strength) of the pearlitic steel by solid-solution strengthening with ferrite. It is also an element for inhibiting softening in heat-affected zones, for instance welding zones, by precipitation strengthening (fine precipitation of Ni_3Ti, intermetallic compound). If the Ni content is less than 0.01 mass%, these effects cannot be readily expected. If the Ni content is more than 1.00 mass%, the ductility of the ferrite phase is drastically lowered, which causes on the rolling contact surface and lowers the surface damage resistance of the rail. Therefore, the Ni content is limited to the range of from 0.01 to 1.00 mass%.

[0040] Ti is a element effective in preventing creation of brittleness of the welded joint portion by increasing the fineness of the structure of heat affected zones which are heated up to the austenite region taking advantage of the insolubility of Ti nitride and Ti carbide precipitated in reheating during welding. If the Ti content is less than 0.0050 mass%, these effects cannot be readily expected. If the Ti content is more than 0.0500 mass%, coarse Ti nitride and Ti carbide are generated, which greatly lowers the ductility and the fatigue-damage resistance of the rail. Thus, the Ti content is limited to the range of from 0.0050 to 0.0500 mass%.

[0041] Mg is an element effective in improving the ductility of the pearlite structure by forming fine oxide bonding with O (oxygen), S (sulfur) or Al, inhibiting grain growth of crystal grains during reheating for rail rolling and for improving the fineness of the austenite grain. Mg is also an element effective in improving the ductility of the pearlite structure by finely dispersing MnS with MgO and/or MgS, forming Mn depleted zones around MnS, expediting the generation of pearlite transformation, and increasing the fineness of the pearlite block size as a result. If the Mg content is less than 0.0005 mass%, these effects cannot be readily expected. If the Mg content is more than 0.0200 mass%, coarse Mg oxide is generated, which greatly lowers the ductility and the fatigue-damage resistance of the rail. Thus, the Mg content is limited to the range of from 0.0005 to 0.0200 mass %.

[0042] Ca is an element effective in improving the ductility of the pearlite structure by forming sulfide CaS (Ca has a strong bonding force with S), finely dispersing MnS with CaS, forming Mn depleted zone around MnS, expediting the generation of pearlite transformation, and increasing the fineness of the pearlite block size as a result. If the Ca content is less than 0.0005 mass%, these effects cannot be expected. If the Ca content is more than 0.0150 mass%, coarse Ca oxide is generated, which lowers the ductility and the fatigue-damage resistance of the rail. Thus, the Ca content is limited to the range of from 0.0005 to 0.0150 mass %.

[0043] Al is an important element as an oxygen scavenger. Al is also an element for shifting the eutectoid transformation temperature toward the side of a higher temperature and for shifting the amount of eutectoid carbon toward the higher side. Al is also an element effective in inhibiting the generation of pro-eutectoid cementite structure and in highly strengthening the pearlite structure. If the Al content is less than 0.0100 mass%, these effects cannot be expected. If the Al content is more than 1.00 mass%, it becomes difficult to dissolve into the steel, which causes generation of coarse aluminum-type inclusions which can be a source of fatigue-damage and lower the ductility and the fatigue-damage resistance of the rail. Also, oxide is formed at welding, which degrades weldability drastically. In view of above, the Al content is limited to the range of from 0.0100 to 1.00 mass %.

[0044] Zr is an element for inhibiting the formation of a segregation zone in the central region of the billet(bloom, slab) and thereby inhibiting generation of pro-eutectoid cementite structures generated in the segregation region of the rail. This is made by increasing the percentage of equiaxed crystals (grains) in the solidification structure, since ZrO_2 inclusions have a good lattice match, and become solidification cores of the high carbon content steel rail of which the primary crystal is γ-Fe, which enables to form high equi-axed crystal rate in the solidification structure. If the Zr content is less than 0.0001 mass%, the number of ZrO_2 inclusions are not enough to work as solidification cores. Consequently a pro-eutectoid cementite structure is generated in the segregation region, which degrades the ductility of the rail. If the Zr content is more than 0.2000 mass%, a great amount of coarse Zr type inclusions are generated, which also degrades the ductility of the rail and generates fatigue damage resulting from the coarse Zr type inclusions. This reduces the life-span of the rail. Consequently, the Zr content is limited to the range of from 0.0001 to 0.2000 mass%.

[0045] N enables the inhibition of grain growth of austenite grain by precipitating V nitride, V-carbonitride and/or Nb-carbonitride during continuous rolling. N is also an element effective in increasing both the ductility and the hardness (strength) of the pearlite structure by precipitating V nitride, V-carbonitride and/or Nb-carbonitride during the cooling process after continuous rolling. Further N is an element effective in preventing heat affected zones of welded joint parts from softening by precipitating V nitride, V-carbonitride and/or Nb-carbonitride in the heat affected zones which is reheated at a temperature range below the Ac1 point. In addition to the above, N is an element effective in improving the ductility of the pearlite structure by forming segregation on the austenite grain boundary, which expedites pearlite transformation from the austenite grain boundary and increases the fineness of the pearlite block size. If the N content is less than 0.0060 mass%, the effects mentioned above are very weak. If the N content is more than 0.0200 mass%, it becomes difficult to dissolve N into the steel to make a solid-solution, which generates bubbles which can be a source of fatigue damage. In view of this, the N content is limited to the range of from 0.0060 to 0.0200 mass%. Usually, steel rail initially includes N as impurity by a maximum of 0.0050 mass%. Consequently, N should be added in amounts sufficient to provide N in amounts within the range of from 0.0060 to 0.0200 mass% to expect the above effects.

[0046] V enables the inhibition of grain growth of austenite grain by precipitating V carbide, V nitride, and/or V-carbonitride during continuous rolling. V is also an element effective in increasing both the ductility and the hardness (strength) of the pearlite structure through precipitation-hardening by precipitating V carbide, V nitride, and/or V-carbonitride during the cooling process after continuous rolling. Further V is an element effective in preventing heat affected zones of welded joint parts from softening by precipitating V carbide, V nitride, and/or V-carbonitride at relatively a high temperature range in the heat affected zones, which are reheated at a temperature range below the Ac1 point. If the V content is less than 0.005 mass%, these effects cannot be significantly expected, i.e. no significant improvement in the ductility and the hardness of the pearlite structure will be achieved. If the V content is more than 0.500 mass%, coarse V carbide, V nitride, and/or V-carbonitride, which can be sources of fatigue-damage, generate and the ductility and the fatigue damage resistance of the rail are degraded. Thus, the V content is limited to the range of from 0.005 to 0.500 mass%.

[0047] Nb enables the inhibition of grain growth of an austenite grain by precipitating Nb carbide, and/or Nb-carbonitride during continuous rolling. Nb is also an element effective in increasing both the ductility and the hardness (strength) of the pearlite structure through precipitation-hardening by precipitating Nb carbide, and/or Nb-carbonitride during the cooling process after continuous rolling. Further, Nb is an element effective in preventing heat affected zones of welded joint parts from softening by precipitating Nb carbide, and/or Nb-carbonitride at temperatures ranging from low to high in the heat affected zones, which are reheated at a temperature range below the Ac1 point. If the Nb content is less than 0.002 mass%, these effects cannot be significantly expected, i.e. no significant improvement in the ductility and the hardness of the pearlite structure can be expected. If the Nb content is more than 0.050 mass%, coarse Nb carbide, and/or Nb-carbonitride, which can be sources of fatigue-damage, generate and the ductility and the fatigue damage resistance of the rail are degraded. Thus, the Nb content is limited to the range of from 0.002 to 0.050 mass %.

[0048] (2) The reason for the limitation on the added amount of V, Nb or N, which enables the inhibition of the grain growth of austenite grain after rolling is as follows. Concerning the above-mentioned V, Nb and N, it is preferable to add these elements in amounts such that (expression 3) below is satisfied. The reason why the added amount of V, Nb or N is limited to the range calculated based on the (expression 3) below concerning V mass%, Nb mass% and N mass% is now explained. The reason is that in continuous rolling of high carbon content steel rail, methods for inhibiting grain growth of austenite grain after rolling by controlling precipitations have been studied. As a result, it was found that the precipitation of V-carbide, V-Nitride, V-carbonitride, Nb-carbide and Nb-carbonitride generated during the continuous rolling causes pinning of austenite grains, which inhibits the growth of austenite grain. In addition, the conditions on which the precipitation of V-carbide, V-Nitride, V-carbonitride, Nb-carbide and Nb-carbonitride during the continuous rolling can be fully controlled was investigated. It was found that the generation of the precipitation has a positive correlation with the added amounts of V, Nb and N.

[0049] Based on the above results, the range of added amounts of V, Nb and N needed to sufficiently inhibit the growth of austenite grain was experimentally investigated. The investigation indicated that the contribution rate by unit amount (mass%) of V, Nb and N (N is added to expedite formation of V-nitride, V-, Nb-carbonitride) was different from each other. Then, the contribution rate was experimentally obtained and the (expression 3) below was derived.

$$PC = V(\text{mass\%}) + 10\times Nb(\text{mass\%}) + 5\times N(\text{mass\%}) \qquad \text{(expression 3)}$$

Using this expression, experiments were carried out with respect to optimal ranges for amounts of V, Nb and N. As a result it was found that if the value of PC defined by the (expression 3) is less than 0.04, the growth of austenite grain after continuous rolling cannot be inhibited since the pinning force with austenite grain was too small; and if the value of PC is more than 0.30, the growth of an austenite grain after continuous rolling cannot be significantly inhibited where the properties of the rail are not adversely affected but coarse V-carbide, Nb-carbide, V-nitride, V-carbonitride, Nb-carbonitride are generated, which degrade the pinning force with austenite. In view of above, the PC value is limited as described in the following expression:

$$0.30 \geqq PC \geqq 0.04.$$

[0050] As mentioned above, N is added in order to expedite the formation of precipitation V-nitride, V-carbonitride, and Nb-carbonitride. Addition of N alone does not form the above precipitations, i.e. there is no effect of inhibiting the growth of the austenite grain. Consequently, in order to inhibit the growth of the austenite grain, addition of V alone, Nb alone, or addition of a combination of V and Nb, V and N, Nb and N, or V, Nb and N can be made. In the case wherein N alone is added, in other words, when neither V nor Nb are added, the value of PC is regarded as 0 (zero) mass%. As mentioned above, steel rail usually contains N as an impurity in an amount of about 0.0050 mass% at maximum. In order to expedite the formation of V-nitride, V-carbonitride, and/or Nb-carbonitride, N is added so that the N content becomes equal to or more than 0.0060 mass%. Therefore, in the calculation of the (expression 3) above, the N content is assumed to be 0 (zero) mass% if the N content is less than 0.0060 mass%.

[0051] (3) The reason for the limitation of the cross-section reduction rate per pass is as follows. The cross-section reduction rate per pass of the rail in the finish rolling is limited to the range of from 2 to 30%. If the cross-section reduction rate of the rail is more than 30%, a great amount of heat is generated, which largely increases the temperature of the rail head surface. This causes the austenite grain of the rail head to become coarse, which makes it difficult to ensure the ductility of the rail. In addition, it also becomes difficult to ensure the formability during rail rolling. If the cross-section reduction rate per pass in the finish rolling is less than 2%, it is not possible to obtain the necessary strain to re-crystallize the austenite grain of the rail head. Therefore, the austenite grain is not fine-grain, which fails to ensure the ductility of the rail. Thus, the cross-section reduction rate per pass in the finish rolling is limited to the range from 2 to 30%.

[0052] The reason for the limitation of the maximum interval time of rolling is as follows. The maximum interval time of rolling (S in seconds) is limited to a time equal to or less than the value calculated from the following two expressions (expression (1) and expression (2) below). The experiment involving two passes of continuous rolling with a 2-30% cross-sectional reduction rate per pass is carried out with respect to high carbon content steel rail while changing the conditions of maximum rolling interval time (S), the carbon content of the steel (C, mass%), and the maximum surface temperature of the rail head (T, °C) and the ductility (total elongation value) of the steel rail was checked by a tensile test. As comparison examples, steel containing the same chemical composition is rolled with the conditions of one pass, a rolling temperature of 950°C and a cross-section reduction rate of 10%, and the ductility (total elongation value) was checked in the same manner.

[0053] FIG.1 shows the results of a continuous rolling experiment. The experimental conditions were: carbon content (C, mass%) of the steel was 1.0 mass%, the cross-section reduction rate was 2-30% per pass, the maximum rolling interval.time (S, seconds) was 0.8 seconds, the number of passes was 2, and the maximum surface temperature of the rail head was changed (T, °C). The vertical axis represents (S×C×T) and the horizontal axis represents the maximum surface temperature of the rail head (T, °C).

[0054] FIG.2 shows the result of another continuous rolling experiment. The experimental conditions were: the carbon content (C, mass%) of the steel was changed, the cross-section reduction rate was 2-30% per pass, the maximum rolling interval time (S, seconds) was 0.8 seconds, the number of passes was 2, and the maximum surface temperature of the rail head was 950°C. The vertical axis represents (S×C×T) and the horizontal axis represents the carbon content (C, mass%).

[0055] FIG.3 shows the results of another continuous rolling experiment. The experimental conditions were: the carbon content (C, mass%) of the steel was 1.0 mass%, the cross-section reduction rate was 2-30% per pass, the maximum rolling interval time (S, seconds) was changed, the number of passes was 2, and the maximum surface temperature of the rail head was 950°C. The vertical axis represents (S×C×T) and the horizontal axis represents the maximum rolling interval time (S, seconds).

[0056] As shown in Figures 1-3, when the value (S×C×T) exceeds 800, improvement of the ductility (total elongation value) becomes insufficient compared to the comparison examples. This result is independent of the change of individual S, C, and T. When the value (S×C×T) exceeds 900, there is no difference in improvement of the ductility (total elongation value) compared to comparison examples. When the value (S×C×T) becomes smaller than 800, the ductility is drastically improved compared to comparison examples.

[0057] Next, the effect of the number of passes in continuous rolling was evaluated. FIG.4 shows the results of another continuous rolling experiment. The experimental conditions were: the carbon content (C, mass%)of the steel was 1.0 mass%, the cross-section reduction rate was 2-30% per pass, the maximum rolling interval time (S, seconds) was 0.5 seconds, the number of passes (P, times) was changed (3-6 passes), and the maximum surface temperature of the rail head (T, °C) was 950°C. As comparison examples, steel containing the same chemical composition was rolled with the conditions of one pass, a rolling temperature of 950°C and a cross-section reduction rate of 10% per pass, and the ductility (total elongation value) was checked in the same manner. The vertical axis represents (S×C×T×P) and the horizontal axis represents the number of passes (P, times) in the continuous finish rolling.

[0058] As shown in Figure 4, when the value (S×C×T×P) exceeds 2400, improvement of the ductility (total elongation value) becomes insufficient compared to the comparison examples. When the value (S×C×T×P) exceeds 2600, there is no difference with improvement of the ductility (total elongation value) compared to the comparison examples. When the value (S×C×T×P) becomes smaller than 2400, the ductility is drastically improved compared to the comparison examples.

[0059] The present inventors have studied the operation conditions of continuous rolling to ensure the ductility (total elongation value) using the correlations described above. In the actual rolling process for producing a commercial rail, it is difficult to change the carbon content of the steel (C, mass%) and the number of passes (P, times) since the wear resistance and the rolling formability have to be ensured. In view of this, the maximum rolling interval time (S, seconds) and the maximum surface temperature of the rail head (T, °C) are controlled. As mentioned above, the maximum rolling interval time (S, seconds) and the ductility (total elongation value) have a correlation. As S increases, both (S×C×T) and (S×C×T×P) are increased, and the ductility (total elongation value) is lowered. The present inventors came up with idea that if the maximum rolling interval time S was kept lower than the values shown below for expressions (1) and (2), which are determined from the relation above, then the ductility (total elongation value) of the steel rail would be improved. As a result of the rolling experiments for commercial rail, it was found that in order to inhibit the growth of austenite grain at inter-stand (standing between consecutive passes) and to increase the fineness of austenite grain after continuous rolling, if the number of passes is 2, the maximum rolling interval time S has to be less than or equal to the value CPT1 calculated from the following (expression 1) consisting of C (mass%) of the carbon content of the steel and T (°C) of the maximum surface temperature of a rail head during the rolling, and if the number of passes is 3 or more, the maximum rolling interval time S has to be less than or equal to the value CPT2 calculated from the following (expression 2) consisting of C (mass%) of the carbon content of the steel, T (°C) of the maximum surface temperature of a rail head during the rolling and P (number of times) of the number of passes.

$$CPT1 = 800/(C \times T) \ldots\ldots\ldots\ldots\ldots\ldots\text{(expression 1)}$$

$$CPT2 = 2400/(C \times T \times P) \ldots\ldots\ldots\ldots\text{(expression 2)}$$

$$S(sec) \leqq CPT1,\ CPT2$$

Definitions:

[0060] The rolling interval time means the time that a blank (billet, bloom, slab) needs to travel from one rolling stand (pass) to next rolling stand (pass), wherein each of the rolling stands is required to be operated with the reduction rate of 2% or more. In other words, if a particular rolling stand in the continuous finish rolling process is operated with the reduction rate less than 2%, the particular stand cannot be taken into account for determining the rolling interval time, but rather be ignored. The maximum rolling interval time means the longest time among the rolling interval times. In the case of 3 passes (3 rolling stands), for example, if the time A taken between first pass and second pass is longer than the time B taken between second pass and third pass, then the time A is the Maximum rolling interval time.

[0061] The surface temperature of the rail head (T, °C) is the surface temperature of the rail head measured between each consecutive pass. The maximum surface temperature of the rail head is the highest temperature among those measured.

[0062] (5) The reason for the limitation of the condition on the rapid cooling of the rail head immediately after hot rolling is as follows. If the cooling rate for cooling the rail head immediately after hot rolling is less than 2°C/sec., the austenite grains become coarse during the cooling, which degrades the ductility of the rail head. If the cooling rate for cooling the rail head immediately after hot rolling is more than 30°C/sec., a large amount of heat recuperation from inside the rail head generates after the rapid cooling, which raises the temperature of the surface of the rail head to form coarse austenite grains and leads to degradation of the ductility. Therefore, the cooling rate for the rail head immediately after hot rolling is limited to the range of 2-30°C/sec.

[0063] As for the temperature range within which the rapid cooling is applied, if the rapid cooling is terminated at a temperature of more than 950°C, austenite grains may significantly grow depending on the carbon content of the steel, which causes coarse grains of austenite and degrades the ductility of the rail head. If the rapid cooling is still applied after the temperature reaches below 750°C, a large amount of heat returning from inside the rail head may generate depending on the rate of cooling, which raises the temperature of the surface of the rail head and generates coarse austenite grains, which lower the ductility. In view of this, the temperature range within which the rapid cooling is applied is limited to the range of 950-750°C.

[0064] (6) The reason for the limitation of the condition on rapid cooling of the head of the rails after hot rolling is as follows. This is a final heat treatment performed after hot rolling. When the temperature of the rail head falls below 700°C, pearlite transformation will commence. Therefore, if the rapid cooling on this stage starts after the temperature of the rail head falls below 700°C, the hardness of the rail head cannot be increased and this will fail to improve the wear resistance. Also, depending on the carbon content and/or alloy elements, pro-eutectoid cementite structures are generated, which degrades the ductility of the rail head. Therefore, the starting temperature for the rapid cooling at the final stage after hot rolling is limited to a temperature higher than 700°C.

[0065] As for the range of the rapid cooling rate, if the rapid cooling rate of the surface of the rail head is less than 2°C/second, no improvement on hardness of the rail head can be seen. Besides, pro-eutectoid cementite may be generated depending on the carbon content and/or alloy elements, which degrades the ductility. And, if the rapid cooling rate is more than 30°C/second, a martensite structure is generated in the present composition system, which significantly degrades the ductility of the rail head. Thus, the rapid cooling rate is limited to a range of 2-30°C/second.

[0066] As for the temperature to which the rapid cooling is terminated, if the rapid cooling is terminated at a temperature of more than 600°C, a large amount of heat returning from inside the rail is generated. As a result, the temperature rise causes pearlite transformation, which leads to the failure of hardening the pearlite structure, i.e., failure of ensuring wear resistance. This also causes the pearlite structure to become coarse, which degrades the ductility of the rail head surface. Therefore, the rapid cooling has to be performed until the temperature reaches at least 600°C. There is no limitation on the lower temperature. However, 400°C is the practical lower limit considering the requirements of ensuring the hardness of the rail head surface and preventing the martensite structure from being formed in the segregation region inside the rail head.

[0067] FIG.5 shows the names of the parts of a rail. Shown are the top of the rail head 1 and the head corner 2. The "surface temperature of the rail head" of the present invention described herein refers to the surface temperature at the top of head 1 and the head corners 2, 2 in FIG.5. By controlling the surface temperature as discussed above, austenite grain can be fine-grained at the rolling and the ductility of the rail is improved. Likewise, the temperatures relating to the heat treatments performed immediately after or after continuous hot rolling, such as the rapid cooling process, refer to the temperature of surface of the top of head 1 and the head corners 2,2, or the temperature of the region within a depth of 5mm from the head surface. By controlling the temperature of this region, a fine-grained pearlite structure having an excellent wear resistance can be obtained.

[0068] In this producing method, coolant used for cooling is not limited. However, air, mist, and a mixture of air and mist are preferable to ensure controlled cooling. The metal structure of the rail head produced by the present invention should preferably be a pearlite structure. A slight amount of pro-eutectoid ferrite structure, pro-eutectoid cementite structure and bainite structure may generate in the pearlite structure depending on the selection of chemical composition and/or selection of rapid cooling conditions. However, a slight amount of these structures in the pearlite structure do not significantly affect the fatigue strength or the ductility. A rail head produced using the present invention can therefore include a slight amount of pro-eutectoid ferrite structure, pro-eutectoid cementite structure and bainite structure.

EXAMPLES

[0069] TABLE 1 shows the chemical composition of the tested steel rails.
TABLE 2 shows the elements (carbon content, PC value), hot rolling conditions, heat treatment conditions, microstructures, hardnesses and total elongation values of tensile test of the rails produced by the methods of the invention from the tested steel rails.
TABLE 3 shows the elements (carbon content, PC value), hot rolling conditions, heat treatment conditions, microstructures, hardnesses and total elongation values of tensile test of the rails produced by conventional methods from the tested steel rails.
[0070] The rails for the examples are as follows:

(1) Rails produced by the methods of the invention (26 rails listed in TABLE 2 denoted by Nos. 1-26).
Rails denoted Nos. 1-4, and 6-15: chemical composition are shown in TABLE 1 and the hot rolling conditions and heat treatment conditions are shown in TABLE 2.
Rails denoted Nos. 5, and 16-26: chemical composition are shown in TABLE 1 and the hot rolling conditions, reheat treatment conditions and PC values are shown in TABLE 2.
(2) Rails produced by methods for comparison (18 rails listed in TABLE 3 denoted by Nos. 27-44).
Rails denoted 27-44: chemical composition are shown in TABLE 1 and the hot rolling conditions are shown in TABLE 3.

[0071]

(1) Tensile test of the head rails
Test Machine: all-purpose miniature tensile test machine
Form of the specimen: Similar to JIS No.4,
Length of parallel part: 25mm,
Diameter of parallel part: 6mm,
The distance for measurement and evaluation of elongation: 21mm,
The portion of rails where specimens were taken: 5mm below the head of the rails (See FIG.6),
The rate of tensile: 10mm/min,
Temperature: room temperature (approx. 20°C)

[0072] The following are explanations based on the examples.
TABLE 1 shows the chemical composition of steel for tested rail examples.
TABLE 2 shows the conditions of hot rolling, cooling after rolling and heat treatment after rolling and the properties of the heads of the rails produced by the method of the present invention.
TABLE 3 shows the conditions of hot rolling, cooling after rolling and heat treatment after rolling and the properties of the heads of the rails produced by conventional methods.
[0073] First, the effects of the hot rolling conditions (the maximum interval time of rolling ≦ values in expressions (1) and (2) above) are explained. The chemical composition of rail 10 in TABLE 2 and rail 32 in TABLE 3 are the same in composition as steel G in TABLE 1, whose carbon content is 1.10 mass%. The value of the total elongation on the tensile test of rail 10 in TABLE 2 is 2.0% higher than that of rail 32 in TABLE 3, the former and the latter being 11.7% and 9.7% respectively. The difference comes from the fact that the maximum interval time of rolling of rail 10 in TABLE 2 is controlled less than expression (2) value and this control makes the austenite structure fine-grained.
[0074] Second, the effects of the PC value are explained. The chemical composition of rail 10 in TABLE 2 and rail 24 in TABLE 2 are the same in composition as steel G in TABLE 1, whose carbon content is 1.10 mass %. The value of the total elongation on the tensile test of rail 24 in TABLE 2 is 1.0% higher than that of rail 10 in TABLE 2, the former and the latter being 12.7% and 11.7%, respectively. The difference comes from the fact that the PC value of rail 10 is not within the range of 0.04-0.30, while the PC value of rail 24 is within the stated range of 0.04-0.30, and this inhibits the growth of the austenite grains after rolling.

[0075] On the other hand, the value of the total elongation on the tensile test of the rail 37 in TABLE 3, whose PC value is not within the range of 0.04-0.30, is deteriorated to 11.0%, because the coarse V-Nb carbide, V nitride, and V-Nb carbonitride are generated if the PC value is not within the stated range. As stated above, the control of the maximum interval time of the rolling must meet expressions (1) or (2) above, and with continuous rolling this improves the ductility of the rails. In addition, control of the PC value within the range of 0.04-0.30 improves the ductility of the rails.

[0076] FIG.7 shows the relationship between the carbon content and the value of the total elongation on the tensile test, which have the most influence on the ductility. As shown in FIG. 7, compared with rails 27-36, produced by a conventional method, rails 1-4 and 6-15, produced by the methods of the present invention have improved ductility on the head of the rails in any amount of carbon content because the maximum interval time of the rolling is controlled. In particular, rails 5 and 16-26 have further improved ductility on the head of rails in any amount of carbon content because not only the maximum interval time of rolling but also the PC value, which is calculated by the equation based on V, Nb, N, is controlled within the required range of 0.04-0.30 in rails 5 and 16-26. Therefore, not only is the austenite structure made fine-grained but also the growth of the austenite grains is inhibited.

[0077] Third, the effects of cooling after rolling are explained. The chemical composition of rail 10 in TABLE 2 and rail 38 in TABLE 3 are the same in composition as steel G in TABLE 1, whose carbon content is 1.10 mass%. The value of the total elongation on the tensile test of rail 10 in TABLE 2 is 2.9% higher than that of rail 38 in TABLE 3, the former and the latter being 11.7% and 8.8%, respectively. The difference comes from the fact that the cooling rate of rail 10 in TABLE 2 is controlled within the inventive range and this control inhibits the growth of the austenite grains, while the cooling rate of rail 38 in TABLE 3 is not controlled.

[0078] The chemical composition of rail 8 in TABLE 2 and rail 39 in TABLE 3 are the same as that of steel F in TABLE 1, whose carbon content is 1.00 mass%. The value of the total elongation on the tensile test of rail 8 in TABLE 2 is 1.7% higher than that of rail 39 in TABLE 3, the former and the latter being 11.2% and 9.5%, respectively. The difference comes from the fact that the temperature of termination of rapid cooling of rail 8 in TABLE 2 is controlled within the inventive range and this control inhibits the growth of the austenite grains, while the temperature of termination of rapid cooling of rail 39 in TABLE 3 is not controlled.

[0079] The chemical composition of rail 10 in TABLE 2 and rail 40 in TABLE 3 are the same in composition as steel G in TABLE 1, whose carbon content is 1.10 mass%. The value of the total elongation on the tensile test of rail 10 in TABLE 2 is 3.2% higher than that of rail 40 in TABLE 3, the former and the latter being 11.7% and 8.5%, respectively. The difference comes from the fact that the temperature of termination of rapid cooling of rail 10 in TABLE 2 is controlled within the inventive range and this control inhibits the growth of the austenite grains, while the temperature of termination of rapid cooling of rail 40 in TABLE 3 is not controlled.

[0080] Fourth, the effects of heat treatment are explained. The chemical composition of rail 2 in TABLE 2 and rail 41 in TABLE 3 are the same in composition as steel A in TABLE 1, whose carbon content is 0.86 mass%. The value of the total elongation on the tensile test of rail 2 in TABLE 2 is 11.5% higher than that of rail 41 in TABLE 3, the former and the latter being 16.5% and 5.0%, respectively. The difference comes from the fact that the cooling rate of rail 2 in TABLE 2 is controlled within the inventive range and this control inhibits the generation of martensite, while the cooling rate of rail 41 in TABLE 3 is not controlled.

[0081] The chemical composition of rail 11 in TABLE 2 and rail 42 in TABLE 3 are the same in composition as steel G in TABLE 1, whose carbon content is 1.10 mass%. The value of the total elongation on the tensile test of rail 11 in TABLE 2 is 4.6% higher than that of rail 42 in TABLE 3, the former and the latter being 11.5% and 6.9%, respectively. The difference comes from the fact that the cooling rate of rail 11 in TABLE 2 is controlled within the inventive range and this control inhibits the precipitation of martensite, while the cooling rate of rail 42 in TABLE 3 is not controlled.

[0082] The chemical composition of rail 13 in TABLE 2 and rail 43 in TABLE 3 are the same as that of steel H in TABLE 1, whose carbon content is 1.10 mass%. The value of the total elongation on the tensile test of rail 13 in TABLE 2 is 5.3% higher than that of rail 43 in TABLE 3, the former and the latter being 11.5% and 6.2%, respectively. The difference comes from the fact that the cooling rate of rail 13 in TABLE 2 is controlled within the inventive range and this control inhibits the pro-eutectoid cementite, while the cooling rate of rail 43 in TABLE 3 is not controlled.

[0083] The chemical composition of rail 5 in TABLE 2 and rail 44 in TABLE 3 are the same in composition as steel D in TABLE 1, whose carbon content is 0.95 mass%. The value of the total elongation on the tensile test of rail 5 in TABLE 2 is 5.6% higher than that of rail 44 in TABLE 3, the former and the latter being 13.2% and 7.6%, respectively. The difference comes from the fact that the temperature of termination of cooling of rail 5 in TABLE 2 is controlled within the inventive range and this control inhibits the coarseness of the grain of pearlite structure, while the temperature of termination of cooling of rail 44 in TABLE 3 is not controlled.

[0084] As stated above, not only is a fine-grain austenite and pearlite structure obtained but also the stable generation of a pearlite structure is obtained by controlling the cooling conditions and the heat treatment conditions after rolling which causes the improvement of ductility (the total elongation value) of the rails.

[0085] Compared with the rails 27-44, rails 1-26 have improved wear resistance and ductility. The mechanisms are as follows:

As for rails 1-26, the maximum interval time of rolling is controlled to be less than the value calculated by the equation based on the carbon content of steel, the maximum head temperature of the rails during continuous rolling and the number of rolling passes and rapid cooling is carried out immediately after rolling. These controls provide a fine-grain austenite structure. In addition, as for rails 1-26, the heat treatment process after rolling at a suitable temperature range and at a suitable cooling rate is carried out. These controls inhibit the generation of pro-eutectoid cementite and martensite, which are detrimental to the ductility of the rails.

[0086] All cited patents, publications, copending applications, and provisional applications referred to in this application are herein incorporated by reference.

[0087] This application claims priority to Application Nos. JP-2004-65676 and JP-2004-285934, filed in Japan on March 9, 2004 and September 30, 2004, respectively, the entire contents of which are herein incorporated by reference.

[0088] The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the present invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

TABLE 1: Chemical Composition of Steels

Steel	Chemical Composition(mass%)	
	C	Si/Mn/Cr/Mo/V/Nb/B/Co/ Cu/Ni/Ti/Mg/Ca/Al/Zr/N
A	0.86	Si:0.25, Mn:0. 65, Cu:0. 25, Co:0.05, Ni:0.25
B	0.90	Si:0.54, Mn:0. 92, Cr:0. 15, N:0.0120
C	0.90	Si:0.22, Mn:0. 75, Cr:0.21 , Ti:0.0150, B:0.0022
D	0.95	Si:0.70, Mn:0.60, Cr:0.55, V:0.03, Nb:0.015
E	1.00	Si:0.40, Mn:0.75, Cr:0.28
F	1.00	Si:0.75, Mn:0.45, Cr:0.55
G	1.10	Si:0.65, Mn:0.70, Cr:0.25, Zr:0.0015
H	1.10	Si:1.20, Mn:1.15, Cr:0.22, Ti:0.0130, Al:0.07
I	1.20	Si:0.65, Mn:0.35, Ca:0.0025
J	1.40	Si:0.25, Mn:0.55, Mg:0.0020, Mo:0.03
K	0.95	Si:0.70, Mn:0.60, Cr:0.55, V:0.03, Nb:0.015, N:0.0080
L	1.00	Si:0.40, Mn:0.75, Cr:0.28, V:0.02, N:0.0060
M	1.00	Si:0.40, Mn:0.75, Cr:0.28, V:0.05, N:0.0080
N	1.00	Si:0.40, Mn:0.75, Cr:0.28, V:0.07
O	1.00	Si:0.75, Mn:0.45, Cr:0.55, V:0.25
P	1.10	Si:0.65, Mn:0.70, Cr:0.25, V:0.07, N:0.0120
Q	1.10	Si:0.65. Mn:0.70, Cr:0.25, Nb:0.015
R	1.10	Si:0.65, Mn:0.70, Cr:0.25, Zr:0.0015, Nb:0.010, N:0.0080
S	1.10	Si:0.65, Mn:0.70, Cr:0.25, Zr:0.0015, V:0.07, Nb:0.015
T	1.20	Si:0.65, Mn:0.35, Ca:0.0025, V:0.06
U	1.40	Si:0.25, Mn:0.55, Mg:0.0020, Mo:0.03, V:0 05, Nb:0.010
V	1.10	Si:0.65. Mn:0.70. Cr:0.25, Zr:0.0015, V:0.10, Nb:0.04
(the balance Fe and unavoidable impurities)		

TABLE 2 (1): Rails produced by the method of the invention

Method	No.	Steel	Carbon content and PC Value		Hot rolling conditions			
			C content C content (mass%)	PC value PC value $V+10\times Nb+5\times N$	Number of rollings P (times)	Range of cross-section reduction (%)	Maximum temperature of rail head (T, deg. C)	(CPT1) 800/CxT
Inventive	1	A	0.86	0.00	2	5~20	1000	0.93
	2	A	0.86	0.00	3	8~24	950	-
	3	B	0.90	0.00	4	10~30	950	-
	4	C	0.90	0.00	2	10~28	920	0.97
	5	D	0.95	0.18	4	10~24	950	-
	6	E	1.00	0.00	2	15~30	950	0.84
	7	E	1.00	0.00	5	8~18	875	-
	8	F	1.00	0.00	5	10~20	1000	-
	9	F	1.00	0.00	6	2~15	900	-
	10	G	1.10	0.00	4	4~25	930	-
	11	G	1.10	0.00	2	10~28	920	0.79
	12	H	1.10	0.00	5	2~25	900	-
	13	H	1.10	0.00	6	5~10	850	-
	14	I	1.20	0.00	5	10~30	900	-
	15	J	1.40	0.00	5	10~30	940	-
	16	K	0.95	0.22	4	10~24	950	-
	17	L	1.00	0.05	5	8~18	875	-
	18	M	1.00	0.09	5	8~18	875	-
	19	N	1.00	0.07	5	8~18	875	-
	20	O	1.00	0.25	6	2~15	900	-
	21	P	1.10	0.13	4	4~25	930	-
	22	Q	1.10	0.15	4	4~25	930	-
	23	R	1.10	0.14	4	4~25	930	-
	24	S	1.10	0.22	4	4~25	930	-
	25	T	1.20	0.06	5	10~30	900	-
	26	U	1.40	0.16	5	10~30	940	-

* 1: structure 2mm under the surface of the head of the rails
* 2: hardness 2mm under the surface of the head of the rails
* 3 : the elongation of the specimen 5mm below the surface of the head of rails at tensile test (See FIG.6)

TABLE 2 (2)

		Cooling condition after rolling		Heat treatment condition after rolling		
(CPT2) 2400/C×T×P	Maximum interval time of rolling (S, spec.)	Cooling rate (°C/sec.) sec.	Temperature of ending cooling (°C)	Temperature of starting heat treatment (°C)	Cooling rate (°C/sec.)	Temperature of ending cooling (°C)
-	0.8	5	900	750	7	580
0.98	0.7	6	945	710	2	520
0.70	0.6	7	900	890	5	510
-	0.6	air cooling after rolling		760	8	530
0.66	0.5	8	870	740	10	480
-	0.7	10	850	930	9	500
0.55	0.4	air cooling after rolling		760	10	480
0.48	0.2	11	835	770	6	510
0.44	0.3	7	820	730	11	450
0.59	0.4	15	820	800	12	450
-	0.6	18	800	750	14	480
0.48	0.3	air cooling after rolling		780	12	465
0.43	0.1	20	780	780	15	500
0.44	0.3	24	780	770	20	550
0.36	0.2	28	760	760	25	480
0.66	0.5	8	870	740	10	480
0.55	0.4	air cooling after rolling		760	10	480
0.55	0.4	air cooling after rolling		760	10	480
0.55	0.4	air cooling after rolling		760	10	480
0.44	0.3	7	820	730	11	450
0.59	0.4	15	820	800	12	450
0.59	0.4	15	820	800	12	450
0.59	0.4	15	820	800	12	450
0.59	0.4	15	820	800	12	450
0.44	0.3	24	780	770	20	550
0.36	0.2	28	760	760	25	480

TABLE 2 (3)

Metallurgical property of head of the rails		
Metallurgy structure of head of rails * 1	Hardness of rails * 2 (Hv)	Total elongation * 3(%)
pearlite	390	15.0
pearlite	342	16.5
pearlite	402	14.5
pearlite	425	14.5

(continued)

Metallurgical property of head of the rails		
Metallurgy structure of head of rails * 1	Hardness of rails * 2 (Hv)	Total elongation * 3(%)
pearlite	445	13.2
pearlite	430	12.5
pearlite	440	11.9
pearlite	420	11.2
pearlite	455	12.4
pearlite	430	11.7
pearlite	450	11.5
pearlite	450	10.5
pearlite	475	11.5
pearlite	440	10.1
pearlite	470	9.0
pearlite	445	14.0
pearlite	450	12.7
pearlite	455	13.2
pearlite	460	12.9
pearlite	470	13.8
pearlite	445	12.1
pearlite	440	12.5
pearlite	440	12.3
pearlite	430	12.7
pearlite	440	11.2
pearlite	470	9.9

TABLE 3 (1): Comparison method

Method	No.	Steel	Carbon content and PC Value		Hot rolling conditions			
			C content (C, mass%)	PC value V+10×Nb+5×N	Numbers of rollings P(times)	Range of cross-section reduction (%)	Maximum temperature of the head of rails (T, °C)	(CPT1) 800/CxT
Comparison	27	A	0.86	0.00	2	5~20	1000	0.93
	28	B	0.90	0.00	4	10~30	950	-
	29	D	0.95	0.18	4	10~24	950	-
	30	E	1.00	0.00	5	8~18	875	-
	31	F	1.00	0.00	6	5~15	900	-
	32	G	1.10	0.00	4	4~25	930	-
	33	G	1.10	0.00	2	10~28	920	0.79
	34	H	1.10	0.00	6	5~10	850	-
	35	I	1.20	0.00	5	10~30	900	-
	36	J	1.40	0.00	5	10~30	940	-
	37	V	1.10	0.50	4	4~25	930	-
	38	G	1.10	0.00	4	4~25	930	-
	39	F	1.00	0.00	5	10~20	1000	-
	40	G	1.10	0.00	4	4~25	930	-
	41	A	0.86	0.00	3	8~24	950	-
	42	G	1.10	0.00	2	10~28	920	0.79
	43	H	1.10	0.00	6	5~10	850	-
	44	D	0.95	0.00	4	10~24	950	-

* 1 : structure 2mm under the surface of the head of the rails
* 2 : hardness 2mm under the surface of the head of the *rails*
* 3 : the elongation of the specimen 5mm below the surface of the head of rails at tensile test (See FIG.6)

TABLE 3 (2)

		Cooling condition after rolling		Heat treatment condition after rolling		
(CPT2) 2400/C×T×P	Maximum interval time of rolling (S, sec.)	Cooling rate (°C /sec.)	Temperature of ending cooling (°C)	Temperature of starting heat treatment (°C)	Cooling rate (°C /sec.)	Temperature of ending cooling (°C)
-	3.0	5	900	750	7	580
0.70	6.0	7	900	890	5	510
0.66	1.2	8	870	740	10	480
0.55	2.0	air cooling		760	10	480
0.44	1.0	7	820	730	11	450
0.59	0.8	15	820	800	12	450

(continued)

		Cooling condition after rolling		Heat treatment condition after rolling		
(CPT2) 2400/C×T×P	Maximum interval time of rolling (S, sec.)	Cooling rate (°C /sec.)	Temperature of ending cooling (°C)	Temperature of starting heat treatment (°C)	Cooling rate (°C /sec.)	Temperature of ending cooling (°C)
-	1.0	18	800	750	14	480
0.43	0.6	20	780	780	15	500
0.44	0.9	24	780	770	20	550
0.36	0.4	28	760	760	25	480
0.59	0.4	15	820	800	12	450
0.55	0.4	2 (slow rate)	820	800	12	450
0.48	0.2	11	960 (high temp.)	770	6	510
0.55	0.4	15	720 low temp.→ high recup.)	700	12	450
0.98	0.7	6	945	710	35 (high rate)	520
-	0.6	1 8	800	680 (low temp.)	14	480
0.43	0.1	20	780	780	1 (low rate)	500
0.66	0.5	8	870	740	10	620 (low tempe.→ high recup.)
temp. = temperature recup.= recuperation						

TABLE 3 (3)

Metallurgical property of head of the rails		
Metallurgy structure of head of rails * 1	Hardness of rails * 2 (Hv)	Total elongation * 3(%)
pearlite	390	13.6
pearlite	402	12.4
pearlite	445	12.1
pearlite	440	10.0
pearlite	455	9.5
pearlite	430	9.7
pearlite	450	9.2
pearlite	475	9.0
pearlite	440	8.2
pearlite	470	7.5
pearlite	430	11.0 (coarse deposition, small ductility improvement)

(continued)

Metallurgical property of head of the rails		
Metallurgy structure of head of rails * 1	Hardness of rails * 2 (Hv)	Total elongation * 3(%)
pearlite(coarse)	430	8.8 (grain growth)
pearlite(coarse)	420	9.5 (grain growth)
pearlite(coarse)	430	8.5 (grain growth)
pearlite + martensite	560	5.0 (ductility deteriorated)
pearlite + initial deposition of cementite	385	6.9 (ductility deteriorated)
pearlite + initial deposition of cementite	345	6.2 (ductility deteriarated)
pearlite (coarse)	336	7.6 (ductility deteriorated)

Claims

1. A method for producing a steel rail having a high content of carbon wherein the rail contains, in mass%,
C: more than 0.85 to 1.40%,
Si: 0.05 to 2.00%,
Mn: 0.05 to 2.00%,
N: 0.0060 to 0.0200%
optionally one or more selected from
Cr: 0.05 to 2.00%,
Mo: 0.01 to 0.50%,
Co: 0.003 to 2.00%,
Cu: 0.01 to 1.00%,
Ni: 0.01 to 1.00%,
Ti: 0.0050 to 0.0500%,
Mg: 0.0005 to 0.0200%,
Ca: 0.0005 to 0.0150%,
Al: 0.0100 to 1.00%,
Zr: 0.0001 to 0.2000,
V: 0.005 to 0.500, and
Nb: 0.002 to 0.050, and
the balance being Fe and unavoidable impurities, comprising:

finish rolling said rail in two consecutive passes, with a reduction rate per pass of a cross-section of said rail of 2-30%,

wherein conditions of said finish rolling satisfy the following relationship:

$$S \leq CPT1$$

wherein CPT1 is the value expressed by the following expression 1

$$CPT1 = 800 / (C \times T) \qquad \text{(expression 1)}$$

Wherein

S is the maximum rolling interval time (seconds), and
(C x T) is defined as follows:

C is the carbon content of the steel rail in mass% and
T is the maximum surface temperature (°C) of a rail head;

said method further comprising:

after said finish rolling process, when the temperature of the rail head is_more than 700°C, cooling the surface of the rail head at a cooling rate of 2-30°C/sec. until the surface temperature reaches at most 600°C, and then allowing the rail to further cool at room temperature.

2. A method for producing a steel rail having a high content of carbon wherein the rail contains, in mass%,
C: more than 0.85 to 1.40%,
Si: 0.05 to 2.00%,
Mn: 0.05 to 2.00%,
N: 0.0060 to 0.0200%
optionally one or more selected from
Cr: 0.05 to 2.00%,
Mo: 0.01 to 0.50%,
Co: 0.003 to 2.00%,
Cu: 0.01 to 1.00%,
Ni: 0.01 to 1.00%,
Ti: 0.0050 to 0.0500%,
Mg: 0.0005 to 0.0200%,
Ca: 0.0005 to 0.0150%,
Al: 0.0100 to 1.00%,
Zr: 0.0001 to 0.2000,
V: 0.005 to 0.500, and
Nb: 0.002 to 0.050, and
the balance being Fe and unavoidable impurities, comprising:

finish rolling said rail in three or more passes, with a reduction rate per pass of a cross-section of said rail of 2-30%,

wherein conditions of said finish rolling satisfy the following relationship:

$$S \leq CPT2 \ .$$

wherein CPT2 is the value expressed by the following expression 2,

$$CPT2 = 2400 / (C \times T \times P) \qquad \text{(expression 2)}$$

Wherein

S is the maximum rolling interval time (seconds), and
(C x T x P) is defined as follows:

C is the carbon content of the steel rail in mass%, and
T is the maximum surface temperature (°C) of a rail head, and P is the number of passes, which is 3 or more;

said method further comprising:

after said finish rolling process, when the temperature of the rail head is more than 700°C, cooling the surface of the rail head at a cooling rate of 2-30°C/sec, until the surface temperature reaches at most 600°C, and then allowing the rail to further cool at room temperature.

3. The method according to claim 1 or claim 2, wherein chemical composition(s) included in said rail meet the following relationship:

$$0.30 \geq V\ (\text{mass}\ \%) + 10 \text{x} Nb\ (\text{mass}\%\ ) + 5 \text{x} N\ (\text{mass}\ \%\ ) \geq 0.04$$

4. The method according to claim 1 or claim 2, further comprising:

immediately after said finish rolling, cooling the surface of said rail head at a cooling rate of 2-30°C/sec. until the surface temperature reaches 950-750°C.

5. The method according to claim 1, 2 or 4, further comprising:

after said cooling step, when the temperature of the.rail head is more than 700°C, cooling the surface of the rail head at a cooling rate of 2-30°C/sec. until the surface temperature reaches at most 600°C; and then allowing the rail to further cool at room temperature.

6. A method for producing a steel rail having a high content of carbon wherein the rail contains, in mass%,
C: more than 0.85 to 1.40%,
Si: 0.05 to 2.00%,
Mn: 0.05 to 2.00%,
B: 0.0001 to 0.0050%,
optionally one or more selected from
Cr: 0.05 to 2.00%,
Mo: 0.01 to 0.50%,
Co: 0.003 to 2.00%,
Cu: 0.01 to 1.00%,
Ni: 0.01 to 1.00%,
Ti: 0.0050 to 0.0500%,
Mg: 0.0005 to 0.0200%,
Ca: 0.0005 to 0.0150%,
Al: 0.0100 to 1.00%,
Zr: 0.0001 to 0.2000%,
N: 0.0060 to 0.0200%,
V: 0.005 to 0.500% and
Nb: 0.002 to 0.050%, and
the balance being Fe and unavoidable impurities, comprising:

finish rolling said rail in two consecutive passes, with a reduction rate per pass of a cross-section of said rail of 2-30%,

wherein conditions of said finish rolling satisfy the following relationship:

$$S \leq CPT1$$

wherein CPT1 is the value expressed by the following expression 1,

$$CPT1 = 800 / (C \text{ x } T) \qquad \text{(expression 1)}$$

wherein

S is the maximum rolling interval time (seconds), and
(C x T) is defined as follows:

C is the carbon content of the steel rail in mass%, and
T is the maximum surface temperature in °C of a rail head.

7. A method for producing a steel rail having a high content of carbon wherein the rail contains, in mass%,
C: more than 0.85 to 1.40%,
Si: 0.05 to 2.00%,
Mn: 0.05 to 2.00%,
B: 0.0001 to 0.0050%,
optionally one or more selected from
Cr: 0.05 to 2.00%,
Mo: 0.01 to 0.50%,
Co: 0.003 to 2.00%,
Cu: 0.01 to 1.00%,
Ni: 0.01 to 1.00%,
Ti: 0.0050 to 0.0500%,
Mg: 0.0005 to 0.0200%,
Ca: 0.0005 to 0.0150%,
Al: 0.0100 to 1.00%,
Zr: 0.0001 to 0.2000%,
N: 0.0060 to 0.0200%,
V: 0.005 to 0.500% and
Nb: 0.002 to 0.050%, and
the balance being Fe and unavoidable impurities, comprising:

finish rolling said rail in three or more passes, with a reduction rate per pass of a cross-section of said rail of 2-30%,

wherein conditions of said finish rolling satisfy the following relationship:

$$S \leq CPT2$$

wherein CPT2 is the value expressed by the following expression 2,

$$CPT2 = 2400 / (C \times T \times P) \qquad \text{(expression 2)}$$

wherein

S is the maximum rolling interval time in seconds, and
(C x T x P) is defined as follows:

C is the carbon content of the steel rail in mass%, and
T is the maximum surface temperature in °C of a rail head, and P is the number of passes, which is 3 or more.

8. The method according to claim 6 or claim 7, wherein chemical composition(s) included in said rail meet the following relationship:

$$0.30 \geq V(\text{mass\%}) + 10 \times Nb(\text{mass\%}) + 5 \times N(\text{mass\%}) \geq 0.04$$

9. The method according to claim 6 or claim 7, further comprising:

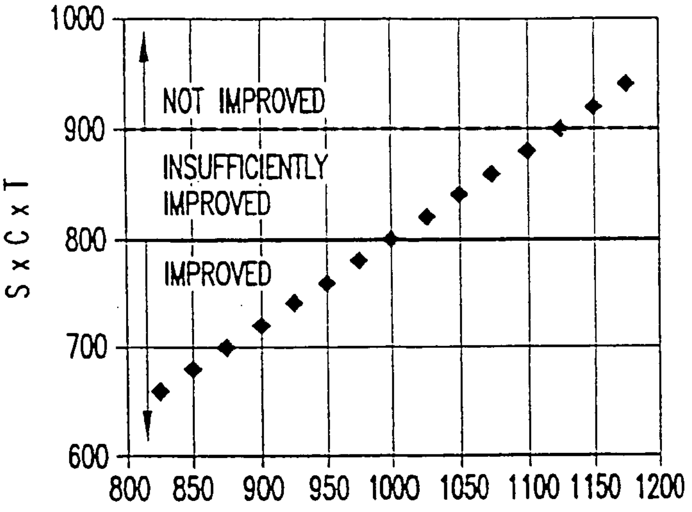
immediately after said finish rolling, cooling the surface of said rail head at a cooling rate of 2-30°C/sec. until the surface temperature reaches 950-750°C.

10. The method according to claim 9, further comprising:

after said cooling step, when the temperature of the rail head is more than 700°C, cooling the surface of the rail head at a cooling rate of2-30°C/sec. until the surface temperature reaches at least 600°C; and then allowing the rail to further cool to room temperature.

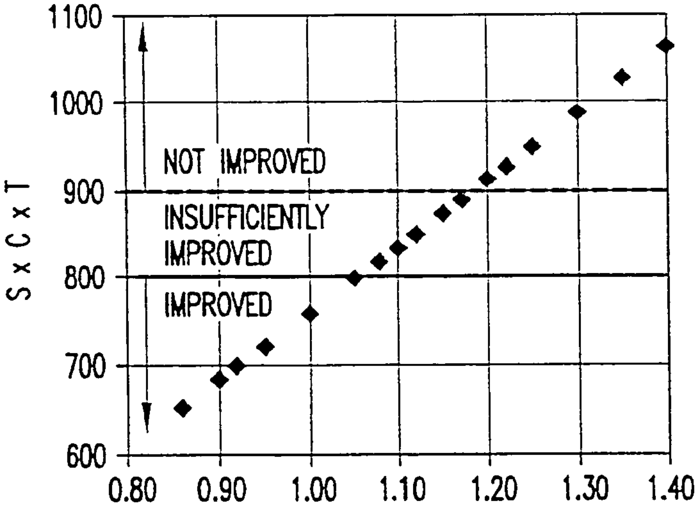
11. The method according to claim 6 or claim 7, further comprising:

after said finish rolling process, when the temperature of the rail head is more than 700°C, cooling the surface of the rail head at a cooling rate of 2-30°C/sec. until the surface temperature reaches at least 600°C, and then allowing the rail to further cool to room temperature.



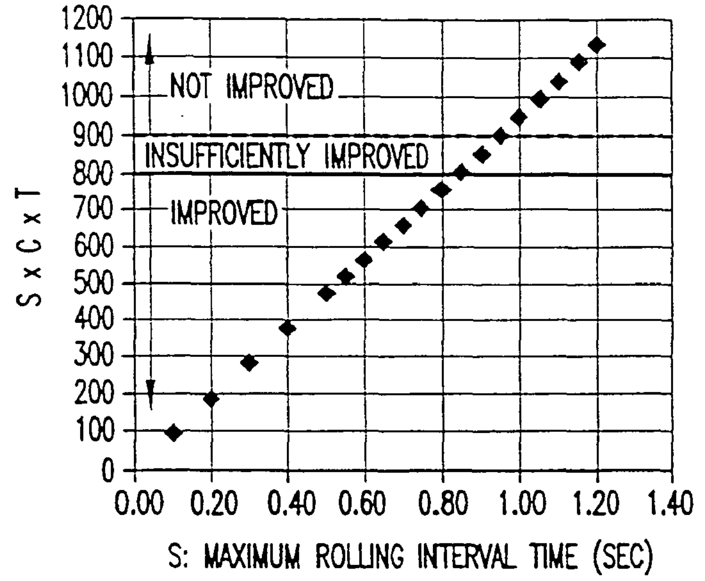
RELATIONSHIP BETWEEN (MAXIMUM SURFACE TEMPERATURE (T)) AND (MAXIMUM ROLLING INTERVAL TIME (S) x CARBON CONTENT (C) x MAXIMUM SURFACE TEMPERATURE OF RAIL HEAD (T))

FIG.1



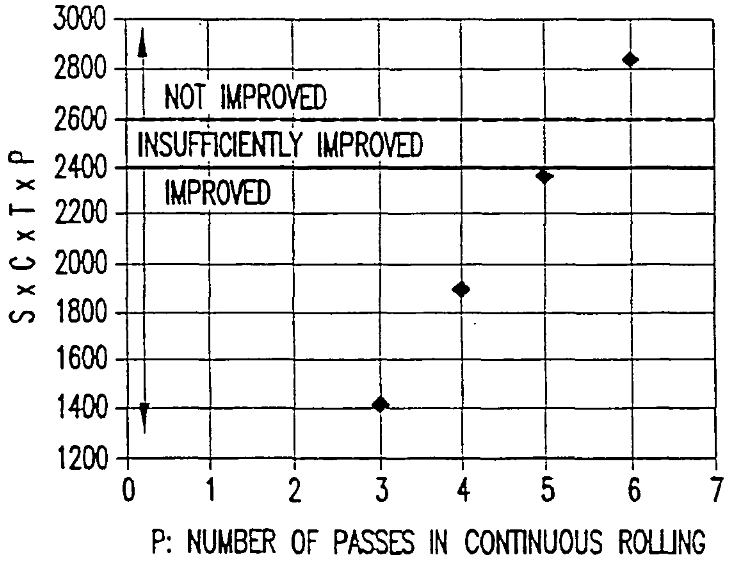
RELATIONSHIP BETWEEN (CARBON CONTENT (C)) AND (MAXIMUM ROLLING INTERVAL TIME (S) x CARBON CONTENT (C) x MAXIMUM SURFACE TEMPERATURE OF RAIL HEAD (T))

FIG.2



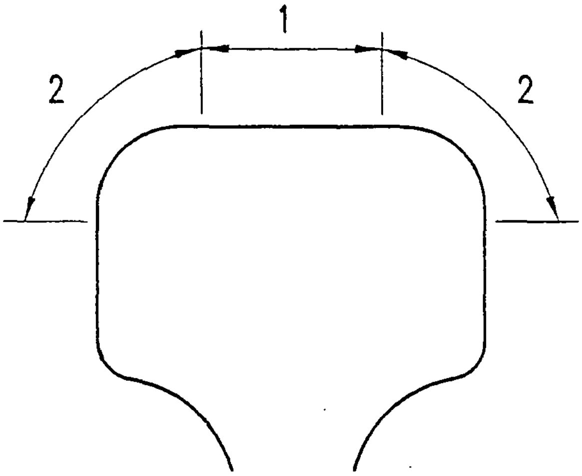
RELATIONSHIP BETWEEN (MAXIMUM ROLLING INTERVAL TIME (S)) AND (MAXIMUM ROLLING INTERVAL TIME (S) x CARBON CONTENT (C) x MAXIMUM SURFACE TEMPERATURE OF RAIL HEAD (T))

FIG.3



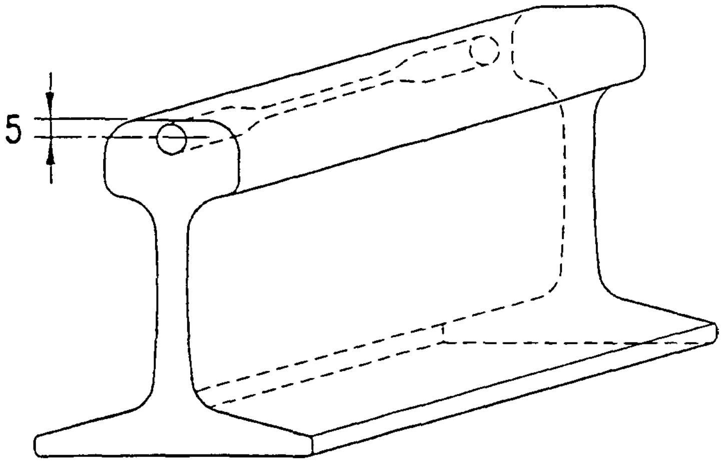
RELATIONSHIP BETWEEN (CARBON CONTENT (C)) AND (MAXIMUM ROLLING INTERVAL TIME (S) x CARBON CONTENT (C) x MAXIMUM SURFACE TEMPERATURE OF RAIL HEAD (T))

FIG.4



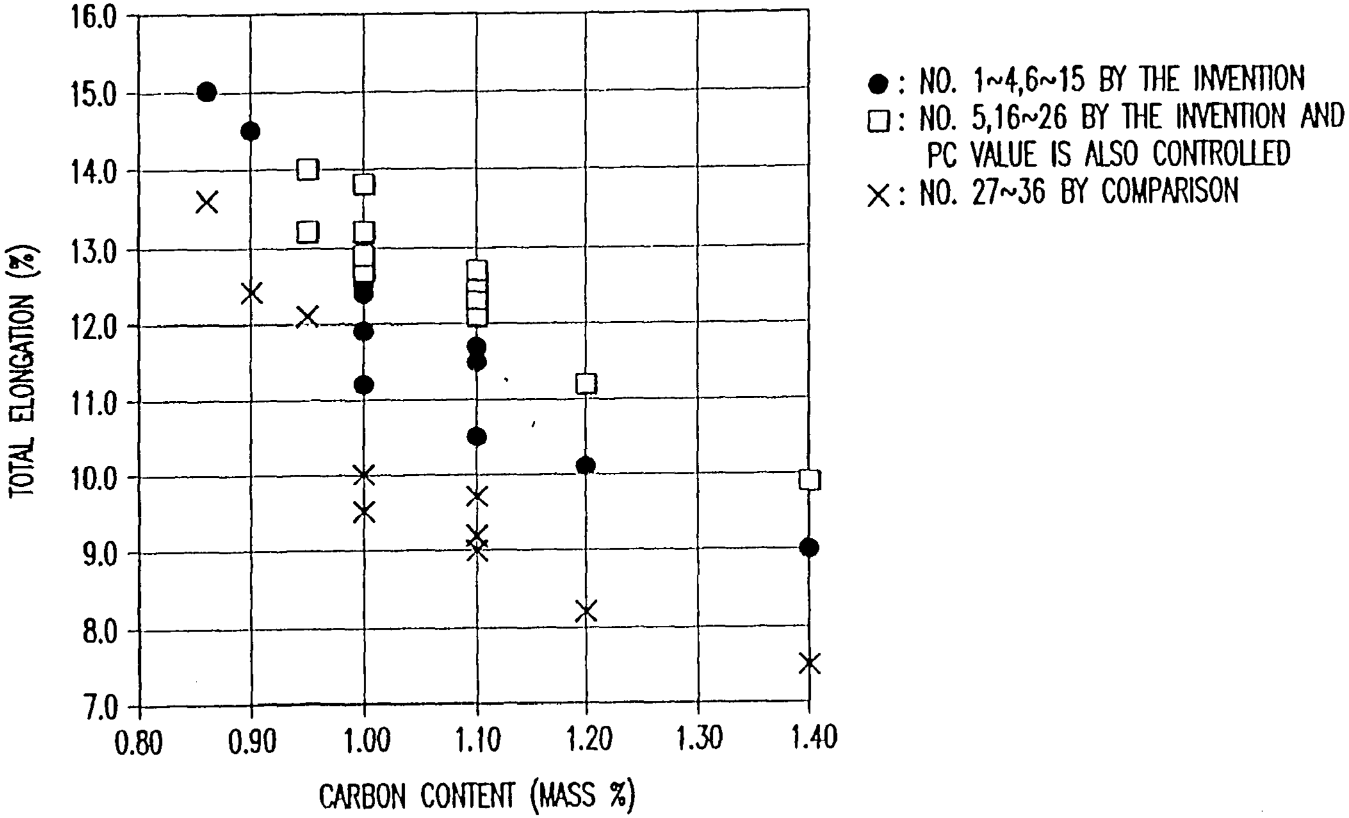
NAME OF PORTIONS OF RAIL

FIG.5



PORTION OF RAIL TAKEN AS SPECIMEN FOR TENSILE TEST

FIG.6



RELATIONSHIP BETWEEN THE CARBON CONTENT AND THE TOTAL ELONGATION VALUE OF THE RAIL

FIG.7

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EUROPEAN SEARCH REPORT

Application Number
EP 09 00 4035

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
D,A	PATENT ABSTRACTS OF JAPAN vol. 2002, no. 12, 12 December 2002 (2002-12-12) & JP 2002 226915 A (NIPPON STEEL CORP), 14 August 2002 (2002-08-14) * abstract * -----	1-11	INV. C21D8/00 B21B1/08
A	EP 0 685 566 A (NIPPON STEEL CORPORATION) 6 December 1995 (1995-12-06) * claim 5 * -----	1-11	
			TECHNICAL FIELDS SEARCHED (IPC)
			C21D B21B C22C

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	6 May 2009	Forciniti, Marco

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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D : document cited in the application
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1

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 09 00 4035

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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06-05-2009

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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