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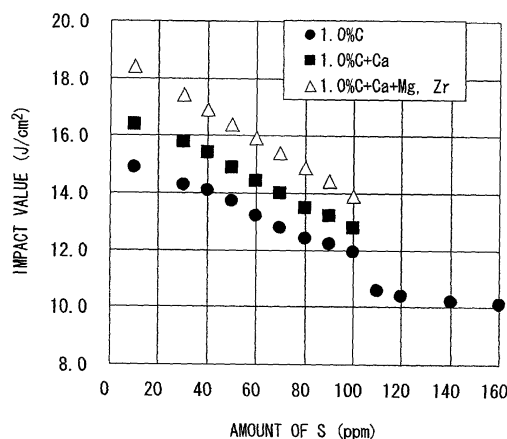
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(54) **PEARLITE RAIL HAVING SUPERIOR ABRASION RESISTANCE AND EXCELLENT TOUGHNESS**

(57) This pearlite rail consists of a steel including: in terms of percent by mass, C: 0.65 to 1.20%; Si: 0.05 to 2.00%; Mn: 0.05 to 2.00%; P ≤ 0.0150%; S ≤ 0.0100%; Ca: 0.0005 to 0.0200%, and Fe and inevitable impurities as the balance, wherein a head surface portion which ranges from surfaces of head corner portions and a head

top portion to a depth of 10 mm has a pearlite structure, a hardness Hv of the pearlite structure is in a range of 320 to 500, and Mn sulfide-based inclusions having major lengths in a range of 10 to 100 μm are present at an amount per unit area in a range of 10 to 200/mm² in a cross-section taken along a lengthwise direction in the pearlite structure.

FIG. 2



Description

TECHNICAL FIELD

[0001] The present invention relates to a pearlite rail used for freight railways in overseas in which both the abrasion resistance (wear resistance) and toughness are improved at the head portion.

The present application claims priority on Japanese Patent Application No. 2008-281847 filed in Japan on October 31, 2008, the content of which is incorporated herein by reference.

BACKGROUND ART

[0002] In conjunction with economic development, new development of natural resources, such as coal or the like, is progressing. Specifically, mining is underway at regions with a severe natural environment which have not so far been developed. Accordingly, the track environment is becoming remarkably severe in overseas freight railways used to transport natural resources. There is a demand for rails to have toughness or the like in regions with cold weather in addition to higher wear resistance than ever. In such circumstances, there is a demand to develop rails having higher wear resistance and higher toughness than those of presently-used high-strength rails.

[0003] In general, it is known that the refinement of a pearlite structure, specifically, grain refining in an austenite structure which is yet to be transformed into pearlite or the refinement of pearlite blocks is effective to improve the toughness of a pearlite steel. In order to achieve grain refining in an austenite structure, during a hot rolling, the rolling temperature is decreased and the rolling reduction rate is increased and, furthermore, a heat treatment by low-temperature reheating after hot rolling of rails is implemented. In addition, in order to achieve the refinement of a pearlite structure, pearlite transformation starting from the inside of austenite grains is accelerated by utilizing transformation nuclei or the like.

However, in the manufacturing of rails, from the viewpoint of ensuring formability during the hot rolling, there are limitations on a decrease in the rolling temperature and an increase in the rolling reduction rate; and thereby, sufficient refinement of austenite grains could not be achieved. In addition, with regard to the pearlite transformation from the inside of austenite grains by utilizing transformation nuclei, there are problems in that the amount of transformation nuclei is difficult to control, and the pearlite transformation from the inside of grains is not stable; and thereby, sufficient refinement of a pearlite structure could not be achieved.

[0004] Due to these problems, a method has been applied to fundamentally improve the toughness of rails having a pearlite structure in which low-temperature reheating is conducted after hot rolling a rail, and then pearlite transformation is performed by accelerated cooling so as to refine a pearlite structure. However, recently, rails have been made to include a high content of carbon for improving the wear resistance; and therefore, there is a problem in that coarse carbides remain inside austenite grains during the above-described low-temperature reheating treatment, which lowers the ductility and toughness of a pearlite structure after the accelerated cooling. In addition, since this method includes reheating, there is another problem in regard to economic efficiency, such as a high manufacturing cost, a low productivity or the like.

[0005] Consequently, there is a demand to develop a method for manufacturing a high-carbon steel rail that ensures the formability during rolling and refines the pearlite structure after hot rolling. In order to solve this problem, methods for manufacturing a high-carbon steel rail shown below have been developed. The major characteristics of those methods for manufacturing a rail are that the fact that austenite grains in a high-carbon steel are easily recrystallized at a relatively low temperature and even with a small rolling reduction rate is utilized so as to refine the pearlite structure. As a result, fine grains with similar grain diameters are obtained by continuous rolling under a small rolling reduction rate; and thereby, the ductility and toughness of a pearlite steel is improved (for example, Patent Documents 1, 2 and 3).

[0006]

Patent Document 1 discloses that a rail having high ductile can be provided by conducting 3 or more continual passes of rolling with a predetermined interval of time in the finish rolling of a high carbon steel rail.

Patent Document 2 discloses that a rail having superior wear resistance and high toughness can be provided by conducting two or more continual passes of rolling with a predetermined interval of time in the finish rolling of a high carbon steel rail, and furthermore, conducting accelerated cooling after the continuous rolling.

Patent Document 3 discloses that a rail having superior wear resistance and high toughness can be provided by conducting cooling between passes of rolling in the finish rolling of a high-carbon steel rail, and conducting accelerated cooling after the continuous rolling.

[0007] The technologies disclosed by Patent Documents 1 to 3 can achieve the refinement of an austenite structure at a certain level and exhibit a slight improvement in toughness by the combination of the temperature, the number of

rolling passes, and the interval of time between passes during the continuous hot rolling. However, there is a problem in that these technologies do not exhibit any effects in regard to fracture starting from inclusions present inside the steel; and thereby, the toughness is not fundamentally improved.

[0008] Furthermore, grain growth rate of an austenite structure is fast in a high-carbon steel. As a result, grains of an austenite structure which are refined by rolling grow after the rolling; and therefore, there is a problem in that the toughness of a heat-treated rail is not improved even in the case where accelerated cooling is conducted.

[0009] Considering these circumstances, the addition of Ca, the reduction of the oxygen content, and the reduction of the Al content have been studied in order to suppress the generation of typical inclusions in rails, that is, MnS or Al_2O_3 . The characteristics of these manufacturing methods are that MnS is changed to CaS by adding Ca in the preliminary treatment of hot metal so as to become harmless, and furthermore, the oxygen content is reduced as much as possible by adding deoxidizing elements or applying a vacuum treatment so as to reduce the amount of inclusions in molten steel, and technologies of which have been studied (for example, Patent Documents 4, 5 and 6).

[0010] The technology in Patent Document 4 discloses a method for manufacturing a high-carbon silicon-killed high-cleanliness molten steel in which the added amount of Ca is optimized to fix S as CaS; and thereby, the amount of elongated MnS-based inclusions is reduced. In this technology, S which segregates and concentrates in a solidification process reacts with Ca which similarly segregates and concentrates or calcium silicate generated in the molten steel; and thereby, S is sequentially fixed as CaS. As a result, the generation of elongated MnS inclusions is suppressed.

[0011] The technology in Patent Document 5 discloses a method for manufacturing a high-carbon high-cleanliness molten steel in which the amount of MnO inclusions is reduced; and thereby, the amount of elongated MnS inclusions precipitated from MnO is reduced. In this technology, a steel is tapped in a non-deoxidized or weakly deoxidized state after being melted in an atmosphere refining furnace, and then a vacuum treatment is conducted at a degree of vacuum of 1 Torr or less so as to make the dissolved oxygen content be in a range of 30 ppm or less. Next, Al and Si are added, and then Mn is added. Thereby, the number of secondary deoxidization products is reduced which will become crystallization nuclei of MnS that crystallizes out in finally solidified portions, and the concentration of MnO in oxides is lowered.

Thereby, the crystallization of MnS is suppressed.

[0012] The technology in Patent Document 6 discloses a method for manufacturing a high-carbon high-cleanliness molten steel with reduced amounts of oxygen and Al in the molten steel. In this technology, a rail having superior damage resistance can be manufactured by limiting the total amount of oxygen based on the relationship between the total oxygen value in oxide-based inclusions and the damage property. Furthermore, the damage resistance of rails can be further improved by limiting the amount of solid-soluted Al or the composition of inclusions in a preferable range.

[0013] The above-described technologies disclosed in Patent Documents 4 to 6 control the configurations and amounts of MnS and Al-based inclusions generated in a bloom stage. However, the configuration of inclusions is altered during hot rolling in the rolling of rails. In particular, Mn sulfide-based inclusions elongated in the lengthwise direction by rolling act as the starting points of fracture in rails; and therefore, there is a problem in that the damage resistance or toughness of rails cannot be stably improved in the case where only the inclusions in the bloom stage is controlled.

[0014] In addition, the application of precipitates has been studied in order to suppress the grain growth of an austenite structure after hot rolling. The characteristics of this manufacturing method are that alloy elements are added and carbonitrides are precipitated so as to pin an austenite structure; and thereby, grain growth is suppressed. Consequently, a heat-treated structure is refined, and toughness is improved (for example, Patent Document 7).

In the technology of Patent Document 7, V and Nb are added, and carbonitrides of V and Nb are precipitated. Furthermore, accelerated cooling is conducted depending on the added amounts of V and Nb, and the grain growth of an austenite structure after hot rolling is controlled; and thereby, a pearlite structure is refined and the toughness of a rail is improved.

[0015] In the technology disclosed in Patent Document 7, alloy elements are added and carbonitrides are precipitated so as to pin an austenite structure; and thereby, grain growth is suppressed. However, the amount of the generated carbonitrides of the alloy elements greatly varies depending on the rolling temperature and the rolling reduction rate. As a result, a huge variation occurs in the effects of suppressing the grain growth, and coarsening of crystal grains occurs partially. Therefore, there is a problem in that the damage resistance and the toughness of rails cannot be stably improved by the carbonitrides of alloy elements alone. In addition, the technology disclosed in Patent Document 7 just achieves the refinement of an austenite structure. This technology has no effect on damages due to Mn sulfide-based inclusions elongated in the lengthwise direction by rolling; and therefore, there is a problem in that the damage resistance and the toughness of rails cannot be stably improved.

[0016] Furthermore, in the technologies disclosed in Patent Documents 4 to 7, embrittlement occurs in a structure due to the alteration in the components of a steel, particularly, the alteration of components mixed therein as impurities. Therefore, there is a problem in that the damage resistance and the toughness of rails cannot be stably improved by controlling inclusions due to the addition of alloy elements and the reduction of the oxygen content, and by refining an austenite structure due to the application of precipitates.

[0017] From such circumstances, it has become desirable to provide a pearlite rail having superior wear resistance and toughness in which both the wear resistance and damage resistance of a pearlite structure are improved.

PRIOR ART DOCUMENTS

Patent Documents

5 **[0018]**

Patent Document 1: Japanese Unexamined Patent Application Publication No. H07-173530
 Patent Document 2: Japanese Unexamined Patent Application Publication No. 2001-234238
 Patent Document 3: Japanese Unexamined Patent Application Publication No. 2002-226915
 10 Patent Document 4: Japanese Unexamined Patent Application Publication No. H05-171247
 Patent Document 5: Japanese Unexamined Patent Application Publication No. H05-263121
 Patent Document 6: Japanese Unexamined Patent Application Publication No. 2001-220651
 Patent Document 7: Japanese Unexamined Patent Application Publication No. 2007-291413

15 **DISCLOSURE OF THE INVENTION**

Problems to be Solved by the Invention

20 **[0019]** The present invention has been made in consideration of the above problems, and the object of the present invention is to provide a pearlite rail in which both wear resistance and toughness are improved at the head portion that are particularly in demand as a rail for freight railways in overseas.

Means for Solving the Problems

25 **[0020]** The present invention has the following features.

A pearlite rail according to the present invention consists of a steel including, in terms of percent by mass, C: 0.65% to 1.20%, Si: 0.05% to 2.00%, Mn: 0.05% to 2.00%, $P \leq 0.0150\%$, $S \leq 0.0100\%$, Ca: 0.0005% to 0.0200%, and Fe and inevitable impurities as the balance. In a head portion of the rail, a head surface portion which ranges from surfaces of head corner portions and a head top portion to a depth of 10 mm has a pearlite structure, and a hardness Hv of the pearlite structure is in a range of 320 to 500. Mn sulfide-based inclusions having major lengths in a range of 10 to 100 μm are present at an amount per unit area in a range of 10 to 200/ mm^2 in a cross-section (a cross-section parallel to the longitudinal direction of the rail) taken along a lengthwise direction in the pearlite structure.

Here, Hv refers to the Vickers hardness defined by JIS B7774.

35 In the pearlite rail according to the present invention, the steel may further include, in terms of percent by mass, either one or both of Mg: 0.0005 to 0.0200% and Zr: 0.0005 to 0.0100%, and Mg-based oxides, Zr oxides, and Mn sulfide-based inclusions having grain diameters in a range of 5 nm to 100 nm may be present at an amount per unit area in a range of 500 to 50,000/ mm^2 in a transverse cross-section (a cross-section parallel to the width direction of the rail) in the pearlite structure.

40 The steel may further include, in terms of percent by mass, one or more of steel components described in the following (1) to (9).

- (1) Co: 0.01% to 1.00%
- (2) either one or both of Cr: 0.01% to 2.00% and Mo: 0.01% to 0.50%
- (3) either one or both of V: 0.005% to 0.50% and Nb: 0.002% to 0.050%
- 45 (4) B: 0.0001% to 0.0050%
- (5) Cu: 0.01 % to 1.00%
- (6) Ni: 0.01% to 1.00%
- (7) Ti: 0.0050% to 0.0500%
- (8) Al: more than 0.0100% to 1.00%
- 50 (9) N: 0.0060 to 0.0200%

Effects of the Invention

55 **[0021]** In accordance with the present invention, the components, structure and hardness of a rail steel are controlled, and, in addition, the contents of P and S are reduced, Ca is added, and the number of Mn sulfide-based inclusions is controlled. Thereby, the wear resistance and toughness of a pearlite structure are improved; and as a result, it is possible to improve the usable period of a rail, particularly, for freight railways in overseas (overseas freight railways). Furthermore, it is possible to further improve the toughness of the pearlite structure by adding Mg and Zr and controlling the number

of fine Mn sulfide-based inclusions and Mg and Zr-based oxides; and as a result, it is possible to further improve the usable period.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022]

FIG. 1 is a view showing nominal designations of portions in a transverse cross-section (a cross-section perpendicular to the lengthwise direction) of the rail steel according to the present invention.

FIG. 2 is a view showing the effects of the addition of Ca and the addition of Mg and Zr on the relationship between the amount of S and the impact value which are results obtained by melting steels in which the amount of S is altered, the amount of P is in a range of 0.0150% or less, the amount of carbon is 1.00%, and Ca, Mg and Zr are added, conducting a laboratory melting and rolling test that simulates equivalent rolling conditions for rails, and conducting an impact test.

FIG. 3 is a view showing the observation location of Mn sulfide-based inclusions in the rail steel according to Claim 1. FIG. 4 is a view showing the observation location of Mn sulfide-based inclusions, Mg-based oxides and Zr oxides in the rail steel according to Claim 2.

FIG. 5 is a view showing the location where the specimens are taken for the wear test.

FIG. 6 is a view showing the outline of the wear test.

FIG. 7 is a view showing the location where the specimens are taken for the impact test.

FIG. 8 is a view showing the relationship between the amount of carbon and the amount of wear in the results of the wear test of the rail steels according to the present invention and the comparative rail steels (Steel Nos. 48, 50, 51, 52, 53, 64, 66 and 67).

FIG. 9 is a view showing the relationship between the amount of carbon and the impact value in the results of the impact test of the rail steels according to the present invention and the comparative rail steels (Steel Nos. 49, 51, 53, 65, 66 and 68).

FIG. 10 is a view showing the relationship between the amount of carbon and the impact value in the results of the impact test of the rail steels according to the present invention and the comparative rail steels (Steel Nos. 54 to 63 and rails with the added amounts of P, S and Ca outside the ranges of the present invention).

FIG. 11 is a view showing the relationship between the amount of carbon and the impact value in the results of the impact test of the rail steels according to the present invention (Steel Nos. 11 to 13, 18 to 20, 24 to 26, 29 to 31, 33 to 35, 36 to 38 and 45 to 47).

BEST MODE FOR CARRYING OUT THE INVENTION

[0023] Hereinafter, as embodiments to carry out the present invention, pearlite rails with superior wear resistance and toughness will be described in detail. Here, the units of the contents of alloy elements are % by mass, and, hereinafter, expressed simply as %.

FIG. 1 shows a cross-section perpendicular to the lengthwise direction of the pearlite rail having superior wear resistance and toughness according to the present invention. A rail head portion 3 includes a head top portion 1 and head corner portions 2 situated at both ends of the head top portion 1. One of the head corner portions 2 is a gauge corner (G. C.) portion that mainly comes into contact with wheels.

A portion ranging from surfaces of the head corner portions 2 and the head top portion 1 to a depth of 10 mm is called a head surface portion 3a (diagonal solid line area). In addition, a portion ranging from the surfaces of the head corner portions 2 and the head top portion 1 to a depth of 20 mm is given a reference number 3b (diagonal dotted line area).

[0024] At first, the inventors of the present invention studied a steel component system having a bad effect on the toughness of rails. A test melting and a hot rolling test which simulated the equivalent hot rolling conditions for rails were conducted using steels of which the contents of P and S were varied while utilizing steels having a varied amount of carbon as a base; and thereby, prototypes of rails were manufactured. Then, the impact values of the prototypes were measured by an impact test, and the effects of the contents of P and S on the impact values were studied.

As a result, with regard to pearlite steels having Hv levels of 320 to 500, it was observed that the impact values were improved in the case where both the contents of P and S were reduced to a certain level or less.

Furthermore, as a result of studying the optimal contents of P and S, it was observed that the impact values were greatly improved in the case where both the contents of P and S were reduced to a certain level or less.

[0025] Next, the inventors of the present invention attempted to clarify the factors dominating the impact values in order to further improve the impact values of rails. As a result, it was observed that rails having low impact values included a lot of Mn sulfide-based inclusions elongated in the lengthwise direction by hot rolling, and these inclusions acted as starting points of fracture.

Then, the inventors of the present invention clarified the generation mechanism of Mn sulfide-based inclusions elongated in the lengthwise direction. When manufacturing rails, a bloom is reheated to a temperature in a range of 1200°C to 1300°C, and then the bloom is subjected to hot rolling. The inventors have investigated the relationship between the hot rolling conditions and the configuration of MnS. As a result, it was observed that, in the case where the rolling temperature was high or in the case where the rolling reduction rate was high during rolling, plastic deformation of soft Mn sulfide-based inclusions easily occurred; and thereby, the Mn sulfide-based inclusions were easily elongated in the lengthwise direction of rails.

[0026] In view of these circumstances, the inventors of the present inventions studied methods to suppress the elongation of Mn sulfide-based inclusions. As a result of conducting test melting and a hot rolling test, it was observed that Mn sulfide-base inclusions were generated from various kinds of oxides as nuclei. Furthermore, as a result of investigating the hardness of oxides and the configurations of Mn sulfide-based inclusions, it was observed that the elongation could be suppressed by hardening inclusions which acted as the nuclei of the Mn sulfide-based inclusions.

Furthermore, the inventors of the present invention studied hard inclusions which acted as the nuclei of Mn sulfide-based inclusions. As a result of conducting a laboratory test using oxides with a high melting point, it was found that Ca with a relative high melting point formed sulfides and oxides, and formed CaO-CaS aggregates. In addition, the inventors have found that, since CaS has a high consistency with Mn sulfide-based inclusions, Mn sulfide-based inclusions were efficiently generated in the aggregates of the oxides and sulfides of Ca (CaO-CaS).

Here, the consistency refers to a difference of lattice constants (interatomic distance) on crystal planes in the crystal structures of two metals. The smaller the difference is, the higher the consistency is. That is, it is considered that two metals are easily bonded.

[0027] Next, the inventors of the present invention conducted test melting and a hot rolling test using steels including Ca in order to verify the above observation. As a result, it was observed that Mn sulfide-based inclusions generated from the aggregates of the oxides and sulfides of Ca (CaO-CaS) acting as the nuclei were rarely elongated after hot rolling; and consequently, the number of Mn sulfide-based inclusions elongated in the lengthwise direction was decreased.

Furthermore, as a result of conducting an impact test using the steels, it was observed that, with regard to steels in which Ca was added and the number of elongated Mn sulfide-based inclusions was small, the occurrence of fracture starting from the elongated Mn sulfide-based inclusions was decreased; and as a result, the impact values were improved.

[0028] In addition, in order to further suppress the elongation of Mn sulfide-based inclusions, the inventors of the present invention studied the relationship between the added amount of Ca and the added amount of S which enable oxides and sulfides to form aggregates by conducting test melting and a hot rolling test. As a result, it was observed that an appropriate number of Ca sulfides were generated and finely dispersed by controlling the ratio of the added amount of S and the added amount of Ca; and consequently, it was possible to further suppress the elongation of Mn sulfide-based inclusions after hot rolling.

[0029] Furthermore, in addition to the suppressing of generation of elongated Mn sulfide-based inclusions having a bad effect on the toughness, the inventors of the present invention studied methods that suppress the grain growth of an austenite structure after hot rolling by using Mn sulfide-based inclusions and oxides. As a result of test melting and a hot rolling test, it was found that it is necessary to finely disperse nano-sized oxides and Mn sulfide-based inclusions, instead of alloy elements formerly used, in an austenite structure as pinning elements in order to stably suppress the grain growth of the austenite structure.

In view of these circumstances, the inventors of the present invention studied methods that finely disperse oxides and Mn sulfide-based inclusions. As a result, it was observed that the oxides of Mg and Zr did not aggregate, but were finely and uniformly dispersed. Furthermore, it was observed that, since both Mg-based oxides and Zr oxides have a good consistency with Mn sulfide-based inclusions, Mn sulfide-based inclusions were also finely dispersed with the fine oxides as the nuclei.

[0030] Next, the inventors of the present invention conducted a hot rolling test using steels including Mg and Zr. As a result, it was observed that nano-sized oxides and Mn sulfide-based inclusions were finely dispersed, and the grain growth of an austenite structure after hot rolling could be suppressed. Furthermore, as a result of conducting an impact test using these steels, it was observed that impact values were improved by the refinement of a pearlite structure in the steels including Mg and Zr.

[0031] The inventors of the present invention conducted a test melting of experimental steels by preparing steels including carbon at a content of 1.00% and P at a content in a range of 0.0150% or less, adding various contents of S, and further adding Ca, Mg and Zr. Next, the inventors conducted a laboratory rolling test which simulated the equivalent rolling conditions for rails so as to manufacture prototypes of rails. Then, the impact values of the prototypes were measured by an impact test, and the effects of the amount of S and the effects of the addition of Ca, Mg and Zr on the impact values were studied. Here, the hardness of the materials was set to an Hv level of 400 by controlling heat treatment conditions.

[0032] FIG. 2 shows the relationship between the amount of S (ppm) and the impact value. With regard to the steels including C at a content of 1.00% (• marks), it was observed that, in the case where the content of P was in a range of

0.0150% or less, the impact values were improved if the content of S was reduced to 0.0100% or less. In addition, from the results of the steels including Ca (■ marks), it was observed that the generation of the elongated Mn sulfide-based inclusions were suppressed by the addition of Ca; and thereby, the impact values were improved. Furthermore, from the results of the steels including Ca, Mg and Zr (Δ marks), it was observed that nano-sized oxides and Mn sulfide-based inclusions were finely dispersed by adding Mg and Zr together with Ca; and thereby, the impact values were remarkably improved.

[0033] Based on the above-described study results, the present invention with the above-described features has been completed. The features of the present invention will be described hereinafter.

(1) The reason why the chemical components of the steels are limited:

The reason why the chemical components of the steels are limited within the above-described numeric ranges in the pearlite rail according to the present invention will be described in detail.

C is an effective element that accelerates pearlite transformation and ensures wear resistance. In the case where the amount of C is less than 0.65%, in the present component system, it is not possible to maintain a minimum level of strength or wear resistance required for rails. In addition, in the case where the amount of C exceeds 1.20%, a large amount of coarse proeutectoid cementite structure is generated; and thereby, wear resistance or toughness is degraded. Therefore, the amount of C is limited to be in a range of 0.65% to 1.20%. Here, it is preferable that the amount of C is in a range of 0.90% or more in order to sufficiently ensure wear resistance.

[0034] Si is an essential element as a deoxidizing material. In addition, Si is an element that increases the hardness (strength) of a rail head portion by solid solution strengthening in the ferrite phase in a pearlite structure. Furthermore, Si is an element that suppresses the generation of proeutectoid cementite structures in hypereutectoid steels; and thereby, a decrease in toughness is suppressed. However, in the case where the amount of Si is less than 0.05%, it is not possible to sufficiently expect such effects. In addition, in the case where the amount of Si exceeds 2.00%, a number of surface defects are generated during hot rolling and weldability is degraded due to the generation of oxides. Furthermore, hardenability is remarkably increased, and a martensite structure is generated which is harmful to the wear resistance and toughness of rails. Therefore, the amount of Si is limited to be in a range of 0.05% to 2.00%. Here, it is preferable that the amount of Si is in a range of 0.20% to 1.30% in order to ensure hardenability and suppress the generation of martensite structure which is harmful to wear resistance or toughness.

[0035] Mn is an element that increases hardenability and refines pearlite lamellar spacing; and thereby, the hardness of the pearlite structure is ensured and wear resistance is improved. However, in the case where the amount of Mn is less than 0.05%, such effects become small, and it becomes difficult to ensure wear resistance necessary for rails. In addition, in the case where the amount of Mn exceeds 2.00%, hardenability is remarkably increased, and martensite structure is easy to generate which is harmful to wear resistance or toughness. Therefore, the amount of Mn added is limited to be in a range of 0.05% to 2.00%. Here, it is preferable that the amount of Mn is in a range of 0.40% to 1.30% in order to ensure hardenability and suppress the generation of martensite structure which is harmful to wear resistance or toughness.

[0036] P is an element inevitably included in steels. The amount of P has a relationship with toughness, and, if the amount of P increases, the pearlite structure is embrittled due to the embrittlement of ferrite phases, and brittle fracture, that is, rail fracture is easy to occur. Therefore, the amount of P is desirably small in order to improve toughness. As a result of experimentally observing the relationship between the impact value and the amount of P, it was observed that, in the case where the amount of P was reduced to 0.0150% or less, the segregation of P was remarkably reduced, the embrittlement of the pearlite structure which was the starting point of fracture was suppressed; and thereby, impact values were greatly improved. From these results, the amount of P is limited to be in a range of 0.0150% or less. The lower limit of the amount of P is not specified; however, about 0.0020% is considered to be the lower limit of the amount of P when actually manufacturing rails in view of dephosphorization capability in a refining process.

Meanwhile, a treatment for lowering the P amount (reduction of the amount of P) is not only accompanied by an increase in refining costs but also by degradation of productivity. As a result, in consideration of economic efficiency, it is preferable that the amount of P is in a range of 0.0030% to 0.0100% in order to stably improve impact values.

[0037] S is an element inevitably included in steels. The amount of S has a relationship with toughness, and if the amount of S increases, stress concentration occurs due to the coarsening of MnS or the increase of density of MnS; and thereby, brittle fracture, that is, rail damage is easy to occur. Therefore, the amount of S is desirably small in order to improve toughness. As a result of experimentally observing the relationship between the impact value and the amount of S, it was observed that, if the amount of S was reduced to 0.0100% or less, the amount of Mn sulfide-based inclusions generated which was the starting point of fracture was reduced, and furthermore, the embrittlement of the pearlite structure was suppressed by the suppression of the elongation of Mn sulfide-based inclusions or the refinement of Mn sulfide-based inclusions due to the addition of Ca, Zr, or Mg. As a result, the impact value was greatly improved. From

these results, the amount of S is limited to be in a range of 0.0100% or less. The lower limit of the amount of S is not specified; however, about 0.0010% is considered to be the lower limit of the amount of S when actually manufacturing rails in view of desulfurization capability in a refining process.

Meanwhile, a treatment for lowering the S amount (reduction of the amount of S) is not only accompanied by an increase in refining costs but also by degradation of productivity. As a result, in consideration of economic efficiency, it is preferable that the amount of S is in a range of 0.0060% or less in order to suppress generation of elongated Mn sulfide-based inclusions and stably improve impact values.

In addition, in order to further improve impact values, it is preferable that the amount of S is in a range of 0.0020% to 0.0035% in order to stably generate fine Mn sulfide-based inclusions which pin the austenite structure and to suppress the generation of elongated Mn sulfide-based inclusions.

[0038] Ca is a deoxidizing and desulfurizing element, and aggregates of the oxides and sulfides of calcium (CaO-CaS) are generated by the addition of Ca. These aggregates act as nuclei for the generation of Mn sulfide-based inclusions; and thereby, the elongation of Mn sulfide-based inclusions is suppressed after hot rolling. Furthermore, nano-sized Mn sulfide-based inclusions are formed from these aggregates as nuclei (formed by utilizing the aggregates as nuclei). Ca is an element having such functional effects. In the case where the amount of Ca is less than 0.0005%, such effects become small, and the aggregates cannot sufficiently act as nuclei for the generation of Mn sulfide-based inclusions. In the case where the amount of Ca exceeds 0.0200%, the amount of independent hard CaO which does not act as the nuclei for Mn sulfide-based inclusions is increased depending on the amount of oxygen in a steel. As a result, the toughness of a rail steel is greatly degraded. Therefore, the amount of Ca is limited to be in a range of 0.0005% to 0.0200%.

Meanwhile, it is preferable that the amount of Ca is in a range of 0.0015% to 0.0150% in order to improve impact values by stably suppressing the generation of elongated Mn sulfide-based inclusions and by suppressing in advance the generation of hard CaO which does not act as the nuclei for Mn sulfide-based inclusions and is harmful to toughness. In addition, in order to further improve impact values, it is necessary to stably generate fine Mn sulfide-based inclusions which pin the austenite structure so as to suppress the coarsening of Mn sulfide-based inclusions. Therefore, it is more preferable that the amount of Ca is in a range of 0.0020% to 0.0080%.

[0039] As described above, S and Ca generate the aggregates of the oxides and sulfides (CaO-CaS). These aggregates act as nuclei for Mn sulfide-based inclusions; and therefore, the aggregates greatly affect the elongation of Mn sulfide-based inclusions. Therefore, it is important to control the amount of S and the amount of Ca. In view of these circumstances, steels with varied amounts of S and Ca were test-melted, and a hot rolling test was conducted. As a result, it was found that, in the case where the ratios of the amount of Ca to the amount of S (S/Ca) were within a specific range, an appropriate number of the oxides and sulfides of Ca were generated and finely dispersed; and thereby, it was possible to further suppress the elongation of Mn sulfide-based inclusions after hot rolling.

Specifically, in the case where the value of S/Ca is less than 0.45, the amount of independent hard CaO which does not act as nuclei for Mn sulfide-based inclusions is slightly increased. As a result, there are cases in which the toughness of rail steels is degraded. In the case where the value of S/Ca exceeds 3.00, the number of the aggregates of sulfides (CaO-CaS) which act as nuclei for Mn sulfide-based inclusions is reduced; and thereby, the elongation of Mn sulfide-based inclusions is promoted. As a result, there are cases in which the toughness of rail steels is degraded. Therefore, it is preferable that the ratio of S/Ca is in a range of 0.45 to 3.00.

[0040] The present invention preferably includes either one or both of Mg and Zr.

Mg is a deoxidizing element that is mainly bonded with O to form a complex of fine nano-sized oxides (MgO) and sulfides (MgS). Nano-sized Mn sulfide-based inclusions are formed from the complexes as nuclei (formed by utilizing the complexes as nuclei). As a result, the grain growth of an austenite structure after hot rolling is suppressed; and thereby, the structure of rail steel is refined. As a result, it is possible to improve the toughness of a pearlite structure. However, in the case where the amount of Mg is less than 0.0005%, the generated amount of the complexes of fine oxides (MgO) and sulfides (MgS) is small; and thereby, the effect of suppressing the grain growth of an austenite structure after hot rolling cannot be sufficiently obtained. In the case where the amount of Mg exceeds 0.0200%, the coarse oxides of Mg are generated; and thereby, the toughness of rails is degraded, and simultaneously, fatigue damage occurs from the coarse oxides. Therefore, the amount of Mg is limited to be in a range of 0.0005% to 0.0200%.

Here, it is preferable that the amount of Mg is in a range of 0.0010% to 0.0050% in order to improve impact values by sufficiently ensuring the generated amount of fine oxides (MgO) which pin an austenite structure and the generated amount of the complexes of the oxides (MgO) and sulfides (MgS) which form nano-sized Mn sulfide-based inclusions, and by sufficiently suppressing the generation of coarse oxides which are harmful to fatigue damage.

[0041] Zr is a deoxidizing element that is mainly bonded with O so as to form fine nano-sized oxides (ZrO₂). These oxides are dispersed finely and uniformly, and furthermore, nano-sized Mn sulfide-based inclusions are formed from the oxides as nuclei (formed by utilizing the oxides as nuclei). As a result, the grain growth of an austenite structure after hot rolling is suppressed; and thereby, the structure of a rail steel is refined. As a result, it is possible to improve the toughness of a pearlite structure. However, in the case where the amount of Zr is less than 0.0005%, the generated

amount of fine oxides (ZrO_2) is small; and thereby, the effect of suppressing the grain growth of an austenite structure after hot rolling cannot be sufficiently obtained. In the case where the amount of Zr exceeds 0.0100%, the coarse oxides of Zr are generated; and thereby, the toughness of rails is degraded, and simultaneously, fatigue damage occurs from the coarse precipitates. Therefore, the amount of Zr added is limited to be in a range of 0.0005% to 0.0100%.

Meanwhile, it is preferable that the amount of Mg is in a range of 0.0010% to 0.0050% in order to improve impact values by sufficiently ensuring the generated amount fine oxides (ZrO_2) which pin an austenite structure and the generated amount of oxides (ZrO_2) which form nano-sized Mn sulfide-based inclusions, and by sufficiently suppressing the generation of coarse oxides which are harmful to fatigue damage.

[0042] If necessary, rails manufactured in the above-described component composition preferably include one or more elements selected from the group consisting of Co, Cr, Mo, V, Nb, B, Cu, Ni, Ti, Al and N for the purpose of the improvement in the hardness (strength) of a pearlite structure or a proeutectoid ferrite structure, the improvement in toughness, the prevention of softening in weld heat-affected zones, and the control of the cross-sectional hardness distribution inside the rail head portion.

[0043] Hereinafter, the main purposes and functional effects of the addition of the above-described elements will be shown.

Co refines a lamellar structure in a rolling contact surface and decreases ferrite grain diameter; and thereby, the wear resistance of a pearlite structure is increased. Cr and Mo increase the equilibrium transformation point, and mainly refine pearlite lamellar spacing; and thereby, the hardness of a pearlite structure is ensured. V and Nb generate carbides and nitrides in a hot rolling process and a subsequent cooling process; and thereby, the growth of austenite grains is suppressed. Furthermore, V and Nb precipitate and harden in a ferrite structure and a pearlite structure; and thereby, the toughness and hardness of a pearlite structure are improved. In addition, V and Nb stably generate carbides and nitrides; and thereby, the softening of welded joint heat-affected zones is prevented.

B reduces the dependency of the pearlite transformation temperature on a cooling rate; and thereby, the hardness distribution in the rail head portion is made uniform. Cu is solid-solubilized in a ferrite structure and in a ferrite phase in a pearlite structure; and thereby, the hardness of the pearlite structure is increased. Ni improves the toughness and hardness of a ferrite structure and a pearlite structure, and simultaneously, Ni prevents the softening of welded joint heat-affected zones. Ti refines the structure in weld heat-affected zones and prevents the embrittlement of welded joint heat-affected zones. Al raises the eutectoid transformation temperature to a higher temperature, and increases the hardness of a pearlite structure. N segregates in austenite grain boundaries; and thereby, pearlite transformation is accelerated. In addition, N refines the size of pearlite blocks; and thereby, toughness is improved.

[0044] Hereinafter, the reason why the amounts of these components are limited will be described in detail.

Co is solid-solubilized in a ferrite phase in a pearlite structure. Thereby, fine ferrite structure formed by the contact with wheels at the rolling contact surface of the rail head portion is further refined; and as a result, wear resistance is improved. In the case where the amount of Co is less than 0.01 %, the refinement of ferrite structure is not achieved; and therefore, it is not possible to expect the effect of improving the wear resistance. In addition, even in the case where the amount of Co exceeds 1.00%, the above-described effect is saturated; and therefore, the refinement of ferrite structure corresponding to the added amount of Co is not achieved. In addition, an increase in the cost for adding alloy elements degrades economic efficiency. Therefore, the amount of Co is limited to be in a range of 0.01% to 1.00%.

[0045] Cr increases the equilibrium transformation temperature, and consequently Cr refines ferrite structure and pearlite structure; and thereby, Cr contributes to an increase of hardness (strength). At the same time, Cr strengthens cementite phase; and thereby, the hardness (strength) of pearlite structure is improved. However, in the case where the amount of Cr is less than 0.01 %, such an effect becomes small, and the effect of improving the hardness of a rail steel is not observed at all. In the case where Cr is excessively added at an amount of more than 2.00%, hardenability is increased, and martensite structure is generated. Thereby, spalling damage starting from the martensite structure occurs in the head corner portions and the head top portion; and as a result, resistance to surface damages is degraded. Therefore, the amount of Cr is limited to be in a range of 0.01 % to 2.00%.

[0046] Mo, similarly to Cr, increases the equilibrium transformation temperature, and consequently Mo refines ferrite structure and pearlite structure; and thereby, Mo contributes to an increase of hardness (strength). Therefore, Mo is an element that improves hardness (strength). However, in the case where the amount of Mo is less than 0.01%, such an effect becomes small, and the effect of improving the hardness of rail steels is not observed at all. In the case where Mo is excessively added at an amount of more than 0.50%, transformation rate is remarkably degraded. Thereby, spalling damage starting from the martensite structure occurs in the head corner portions and the head top portion; and as a result, resistance to surface damages is degraded. Therefore, the amount of Mo is limited to be in a range of 0.01% to 0.50%.

[0047] V refines austenite grains due to the pinning effect of V carbides and V nitrides in the case where a heat treatment is conducted at high temperatures. Furthermore, V increases the hardness (strength) of ferrite structure and pearlite structure due to the precipitation hardening of V carbides and V nitrides generated in the cooling process after hot rolling, and simultaneously, V improves toughness. V is an effective element to obtain those effects. In addition, in

heat-affected portions that are reheated to a temperature in a range of Ac1 or less, V is an effective element to prevent the softening of welded joint heat-affected zones by generating V carbides and V nitrides in a relatively high temperature range. However, in the case where the amount of V is less than 0.005%, such an effect cannot be sufficiently expected, and the improvement in the hardness and the toughness of the ferrite structure and the pearlite structure is not observed.

In the case where the amount of V exceeds 0.50%, the precipitation hardening of the carbides and nitrides of V becomes excessive, and the toughness of the ferrite structure and the pearlite structure is degraded. Thereby, spalling damage occurs in the head corner portions and the head top portion; and as a result, resistance to surface damages is degraded. Therefore, the amount of V is limited to be in a range of 0.005% to 0.50%.

[0048] Nb, similarly to V, refines austenite grains due to the pinning effect of Nb carbides and Nb nitrides in the case where a heat treatment is conducted at high temperatures. Furthermore, Nb increases the hardness (strength) of ferrite structure and pearlite structure due to the precipitation hardening of Nb carbides and Nb nitrides generated in the cooling process after hot rolling, and simultaneously, Nb improves toughness. Nb is an effective element to obtain those effect. In addition, in heat-affected portions that are reheated to a temperature in a range of Ac1 or less, Nb is an effective element to prevent the softening of welded joint heat-affected zones by stably generating the carbides of Nb and the nitrides of Nb from a low temperature range to a high temperature range. However, in the case where the amount of Nb is less than 0.002%, such an effect cannot be expected, and the improvement in the hardness and the toughness of the ferrite structure and the pearlite structure is not observed. In the case where the amount of Nb exceeds 0.050%, the precipitation hardening of the carbides and nitrides of Nb becomes excessive, and the toughness of ferrite structure and the pearlite structure is degraded. Thereby, spalling damage occurs in the head corner portions and the head top portion; and as a result, resistance to surface damages is degraded. Therefore, the amount of Nb is limited to be in a range of 0.002% to 0.050%.

[0049] B forms iron borocarbides ($\text{Fe}_{23}(\text{CB})_6$) in austenite grain boundaries, and B accelerates pearlite transformation. This effect of accelerating pearlite transformation reduces the dependency of the pearlite transformation temperature on a cooling rate; and thereby, more uniform hardness distribution is achieved from the head surface portion to the inside portion of a rail. Therefore, it is possible to extend the usable period of the rail. In the case where the amount of B is less than 0.0001 %, those effects are not sufficient, and improvement of the hardness distribution in the rail head portion is not observed. In the case where the amount of B exceeds 0.0050%, coarse iron borocarbides are generated; and thereby, toughness is degraded. Therefore, the amount of B is limited to be in a range of 0.0001% to 0.0050%.

[0050] Cu is an element that is solid-solubilized in a ferrite structure and in a ferrite phase in a pearlite structure, and Cu improves the hardness (strength) of the pearlite structure due to solid solution strengthening. In the case where the amount of Cu is less than 0.01%, those effects cannot be expected. In the case where the amount of Cu exceeds 1.00%, martensite structure, which is harmful to toughness, is generated by the remarkable improvement of hardenability. Thereby, spalling damage occurs in the head corner portions and the head top portion; and as a result, resistance to surface damages is degraded. Therefore, the amount of Cu is limited to be in a range of 0.01 % to 1.00%.

[0051] Ni is an element that improves toughness of a ferrite structure and a pearlite structure, and simultaneously, Ni increases hardness (strength) by solid solution strengthening. Furthermore, Ni finely precipitates intermetallic compound of Ni_3Ti , which is a complex compound with Ti, in weld heat-affected zones; and thereby, softening is suppressed by precipitation strengthening. In the case where the amount of Ni is less than 0.01 %, those effects are extremely small. In the case where the amount of Ni exceeds 1.00%, toughness of a ferrite structure and a pearlite structure is remarkably degraded. Thereby, spalling damage occurs in the head corner portions and the head top portion; and as a result, resistance to surface damages is degraded. Therefore, the amount of Ni is limited to be in a range of 0.01 % to 1.00%.

[0052] Ti is an effective element that refines the structure of heat-affected zones which are heated to an austenite range by utilizing the fact that carbides of Ti and nitrides of Ti, which are precipitated during the reheating in welding, are not melted; and thereby, Ti prevents the embrittlement of welded joint portions. However, in the case where the amount of Ti is less than 0.0050%, those effects are small, and in the case where the amount of Ti exceeds 0.0500%, coarse carbides of Ti and nitrides of Ti are generated; and thereby, toughness of a rail is degraded. At the same time, fatigue damage occurs due to coarse precipitates. Therefore, the amount of Ti is limited to be in a range of 0.0050% to 0.050%.

[0053] Al is an essential element as a deoxidizing material. In addition, Al is an element that raises the eutectoid transformation temperature to a higher temperature, and Al contributes to an increase in the hardness (strength) of a pearlite structure. In the case where the amount of Al is 0.0100% or less, those effects are small. In the case where the amount of Al exceeds 1.00%, it becomes difficult to solid-solubilize Al in a steel; and thereby, coarse alumina-based inclusions are generated. Thereby, toughness of a rail is degraded, and simultaneously, fatigue damage occurs due to coarse precipitates. Furthermore, oxides are generated during welding; and thereby, weldability is degraded remarkably. Accordingly, the amount of Al is limited to be in a range of more than 0.0100% to 1.00%.

[0054] N segregates in austenite grain boundaries; and thereby, N accelerates ferrite transformation and pearlite transformation from the austenite grain boundaries. As a result, the size of pearlite blocks is mainly refined; and thereby, it is possible to improve toughness. However, in the case where the amount of N is less than 0.0060%, those effects

are small. In the case where the amount of N exceeds 0.0200%, it becomes difficult to solid-solubilize N in a steel. As a result, air bubbles which act as the starting points of fatigue damage are generated; and thereby, fatigue damage occurs inside the rail head portion. Therefore, the amount of N is limited to be in a range of 0.0060% to 0.0200%.

[0055] (2) The reasons why the regions and hardness of pearlite structure in the rail head surface portion 3a are limited: Next, the reasons why the head surface portion 3a of a rail includes a pearlite structure and the hardness Hv thereof is limited to be in a range of 320 to 500 will be described.

At first, the reason why the hardness Hv of a pearlite structure is limited to be in a range of 320 to 500 will be described. In the present component system, in the case where the hardness Hv of the pearlite structure is less than 320, it becomes difficult to ensure the wear resistance of the head surface portion 3a of the rail; and thereby, the usable period of the rail is reduced.

In addition, flaking damage occurs in the rolling contact surface due to plastic deformation; and thereby, the resistance to surface damages in the rail head surface portion 3a is greatly degraded. In addition, in the case where the hardness Hv of a pearlite structure exceeds 500, the toughness of the pearlite structure is greatly degraded; and thereby, the damage resistance in the rail head surface portion 3a is degraded. Therefore, the hardness Hv of the pearlite structure is limited to be in a range of 320 to 500.

[0056] Next, the reason why a range necessary to include a pearlite structure having a hardness Hv in a range of 320 to 500 is limited to the head surface portion 3a of a rail steel will be described.

Here, the head surface portion 3a of a rail refers to, as shown in FIG. 1, a portion ranging from surfaces of the head corner portions 2 and the head top portion 1 to a depth of 10 mm (diagonal solid line area). If a pearlite structure having the above-described components is disposed in the head surface portion 3a, abrasion due to the contact with wheels is suppressed; and thereby, the wear resistance of the rail is improved.

[0057] In addition, it is preferable to dispose a pearlite structure having a hardness Hv in a range of 320 to 500 in a portion 3b ranging from the surfaces of the head corner portions 2 and the head top portion 1 to a depth of 20 mm, that is, at least in the diagonal dotted line area in FIG. 1. Thereby, wear resistance is further ensured even in the case where abrasion occurs in the deeper inside of the rail head portion due to the contact with wheels; and thereby, the usable period of rails is improved. Therefore, it is preferable to dispose a pearlite structure having a hardness Hv in a range of 320 to 500 at or in the vicinity of the surface of the rail head portion 3, with which the wheels mainly contact, and other portions may be a metallographic structure other than the pearlite structure.

Meanwhile, with regard to a method to obtain a pearlite structure having a hardness Hv in a range of 320 to 500 at or in the vicinity of the surface of the rail head portion 3, as described below, it is preferable to conduct an accelerated cooling on a rail head portion 3 including an austenite region in a high-temperature state after hot rolling or reheating.

[0058] Among the rail head portion 3 in the present invention, it is preferable that the metallographic structure in the head surface portion 3a or in the portion 3b which ranging to a depth of 20 mm and including the head surface portion 3a consists of the above-described pearlite structure. However, depending on the component compositions of a rail and the conditions of heat treatments and manufacturing methods, there are cases in which the pearlite structure is mixed with proeutectoid ferrite structure, proeutectoid cementite structure, bainite structure and martensite structure at a small amount, for example, an area ratio of 5% or less. Even in the case where the above-described structures are contained at a content of 5% or less, these structures do not have a major adverse affect on the wear resistance and the toughness of the rail head portion 5. Therefore, the above-described pearlite structure may include structures mixed with proeutectoid ferrite structure, proeutectoid cementite structure, bainite structure, martensite structure or the like at an area ratio of 5% or less.

In other words, among the rail head portion 5 in the present invention, 95% or more of the metallographic structure in the head surface portion 3a or the portion 3b ranging to a depth of 20 mm and including the head surface portion 3a needs to be a pearlite structure, and it is preferable that 98% or more of the metallographic structure in the head portion be a pearlite structure in order to sufficiently ensure wear resistance and toughness.

Meanwhile, in the columns of 'Microstructure' in Tables 1 and 2 below, the description 'small amount' refers to a content of 5% or less, and structures other than a pearlite structure without the description 'small amount' mean that the structures are included at an amount of more than 5% (out of the range of the present invention).

[0059] (3) The reason why the number (per unit area) of Mn sulfide-based inclusions having major axes (major lengths) in a range of 10 μm to 100 μm is limited:

The reason why, in the present invention, the length of the major axis (major length) of Mn sulfide-based inclusions in an arbitrary cross-section taken along the lengthwise direction, which are evaluation subjects, is limited to be in a range of 10 μm to 100 μm will be described in detail.

As a result of investigating the length of the major axis of Mn sulfide-based inclusions and the actual damage performance of actual rails (damage status when actually using rails), in the present component system, it was observed that the fracture of rails occurred from the end portions of Mn sulfide-based inclusions, at which stress concentration occurred. In view of these circumstances, steels were test-melted to include Mn sulfide-based inclusions having various lengths of the major axis, and a hot rolling test was conducted. As a result, it was observed that there was a good relationship

between the number of Mn sulfide-based inclusions having lengths of the major axis in a range of 10 μm to 100 μm and the damage resistance of the rail. Consequently, the length of the major axis of Mn sulfide-based inclusions eligible for the evaluation subjects to count the numbers is limited to be in a range of 10 μm to 100 μm .

[0060] Meanwhile, Mn sulfide-based inclusions having a long length of the major axis, in which stress concentration occurs remarkably, have a large effect on damage resistance, and Mn sulfide-based inclusions having a short length of the major axis have a small effect on the damage resistance. However, in the steel according to the present invention, there are a small number of Mn sulfide-based inclusions having a length exceeding 100 μm , which are not suitable to identify the characteristics of the steels. And Mn sulfide-based inclusions having a length of less than 10 μm have a small effect on the damage resistance. Therefore, Mn sulfide-based inclusions having the above-described lengths of the major axis (major lengths) are used as evaluation subjects.

[0061] Next, the reason why the number (per unit area) of Mn sulfide-based inclusions having major lengths in a range of 10 μm to 100 μm in an arbitrary cross-section taken along the lengthwise direction (a cross-section parallel to the longitudinal direction of a rail) is limited to be in a range of 10 / mm^2 to 200 / mm^2 will be described in detail.

In the case where the total number (per unit area) of Mn sulfide-based inclusions having major lengths in a range of 10 μm to 100 μm exceeds 200 / mm^2 , in the present component system, the number of Mn sulfide-based inclusions becomes excessive; and thereby, the possibility of rail damage increases due to the generation of stress concentration at or in the vicinity of the inclusions. Even in terms of the mechanical characteristics of the steel, it is not possible to improve the impact value. In the case where the total number (per unit area) of Mn sulfide-based inclusions having major lengths in a range of 10 μm to 100 μm is less than 10 / mm^2 , in the present component system, trap sites which absorb inevitable hydrogen remaining in the steel are remarkably reduced. Thereby, the possibility of inducing hydrogenous defects (hydrogen embrittlement) increases; and thereby, the damage resistance of the rail is impaired. As a result, the total number (per unit area) of Mn sulfide-based inclusions having major lengths in a range of 10 μm to 100 μm is limited to be in a range of 10 / mm^2 to 200 / mm^2 .

Meanwhile, in the present limitation, the Mn sulfide-based inclusions refer to both of Mn sulfide-based inclusions generated from aggregates of oxides and sulfides of calcium (CaO-CaS) as nuclei and other Mn sulfide-based inclusions as evaluation subjects.

[0062] In addition, with regard to the number of Mn sulfide-based inclusions, a sample is taken from a cross-section taken along the lengthwise direction of the rail head portion 3, in which the rail damage becomes obvious as shown in FIG. 3, and the measurement of sulfide-based inclusions is conducted. The cross-section in the lengthwise direction of the rail of each of the taken samples is mirror-polished, and Mn sulfide-based inclusions are investigated on an arbitrary cross-section with an optical microscope. Then, the number of inclusions having the above-limited sizes is counted and calculated as the number per unit cross-section area. The typical value of each rail steel is obtained from the average value of the numbers per unit cross-section area of these 20 viewing fields. The location (portion) to be used to investigate Mn sulfide-based inclusions is not particularly limited; however, it is preferable to observe a portion ranging from the surface of the rail head portion 5, which acts as the starting point of damage, to a depth of 3 to 10 mm.

In addition, in order to stably improve fracture resistance of a rail by further decreasing the effect of Mn sulfide-based inclusions which act as the starting points of fracture and by suppressing hydrogenous defects in advance, it is preferable to control the total number (per unit area) of Mn sulfide-based inclusions having major lengths in a range of 10 μm to 100 μm to be in a range of 20/ mm^2 to 180/ mm^2 .

[0063] (4) The reason why the number (per unit area) of Mg-based oxides, Zr oxides and Mn sulfide-based inclusions having grain diameters in a range of 5 nm to 100 nm is limited:

In the present invention, it is preferable that Mg-based oxides, Zr oxides, and Mn sulfide-based inclusions having grain diameters in a range of 5 nm to 100 nm are present at an amount per unit area in a range of 500/ mm^2 to 50,000/ mm^2 in an arbitrary transverse cross-section.

The reason why the grain diameters of Mg-based oxides, Zr oxides and Mn sulfide-based inclusions, which are evaluation subjects, is limited to be in a range of 5 nm to 100 nm will be described in detail.

In the case where the grain diameters of Mg-based oxides, Zr oxides and Mn sulfide-based inclusions is in a range of from 5 nm to 100 nm, a sufficient pinning effect is obtained in grain boundaries when they are generated in an austenite structure. Thereby, it was observed that, without adversely affecting the damage resistance of a rail, consequently, a pearlite structure was refined; and thereby, toughness was reliably improved. Therefore, the grain diameters of Mg-based oxides, Zr oxides and Mn sulfide-based inclusions eligible for the evaluation subjects is limited to be in a range of 5 nm to 100 nm.

Meanwhile, with regard to the pinning effect, the more inclusions having fine grain diameters are present, the larger the effect becomes. However, with regard to Mg-based oxides, Zr oxides and Mn sulfide-based inclusions having grain diameters in a range of less than 5 nm, it is extremely difficult to measure the number thereof. In addition, with regard to Mg-based oxides, Zr oxides and Mn sulfide-based inclusions having grain diameters in a range of more than 100 nm, the above-described pinning effect cannot be obtained. Therefore, Mg-based oxides, Zr oxides and Mn sulfide-based inclusions having the above-described grain diameters are used as evaluation subjects.

[0064] Next, regarding the preferable configurations, the reason why the amount (number) (per mm²) of Mg-based oxides, Zr oxides and Mn sulfide-based inclusions having grain diameters in a range of 5 nm to 100 nm in an arbitrary cross-section in the lengthwise direction is limited to be in a range of 500 to 50,000 will be described in detail.

In the case where the total number (per unit area) of Mg-based oxides, Zr oxides and Mn sulfide-based inclusions having grain diameters in a range of 5 nm to 100 nm is less than 500/mm², the pinning effect is not sufficiently obtained in an austenite structure after hot rolling. As a result, a pearlite structure becomes coarsened, and toughness of the rail is not improved. In the case where the total number (per unit area) of Mg-based oxides, Zr oxides and Mn sulfide-based inclusions having grain diameters in a range of 5 nm to 100 nm exceeds 50,000/mm², precipitation occurs excessively, and a pearlite structure becomes embrittled; and thereby, the toughness of the rail is degraded. Therefore, the total number (per unit area) of Mg-based oxides, Zr oxides and Mn sulfide-based inclusions having grain diameters in a range of 5 nm to 100 nm is limited to be in a range of 500/mm² to 50,000/mm².

[0065] Meanwhile, in the present limitation, the Mg-based oxides and the Zr oxides refer to oxides partially including complex oxides such as Mn sulfide or the like. In addition, the Mn sulfide-based inclusions refer to inclusions generated from fine oxides such as Mg oxides, Zr oxides, Ca oxides or the like, as nuclei.

The grain diameter and the number of the Mg-based oxides, the Zr oxides and the Mn sulfide-based inclusions are observed and measured in the following manner. At first, a thin film is taken from an arbitrary transverse cross-section shown in FIG. 4, and the thin film is observed at a magnification of 50,000 to 500,000 using a transmission electron microscope. The grain diameter of precipitates is obtained by measuring the area of each precipitate through observation and calculating the diameter of a circle having the same area as that of the precipitate.

The precipitates are observed at 20 viewing fields, and the number of precipitates having diameters in a predetermined range of 5 nm to 100 nm is counted, and the number per unit area is calculated from the counted number. The typical value of a rail steel is obtained from the average value of these 20 viewing fields. Meanwhile, the location (portion) to be used to investigate the Mg-based oxides, the Zr oxides, and the Mn sulfide-based inclusions is not particularly limited; however, it is preferable to observe a portion ranging from the surface of the rail head surface portion 3a to a depth of 3 mm to 10 mm, which requires toughness.

[0066] (5) Method for manufacturing the rail steel (rail) according to the present invention:

The method for manufacturing the rail steel according to the present invention including the above-described component composition and microstructure is not particularly limited; however, in general, the rail steel is manufactured by the following method. At first, melting is conducted so as to obtain molten steel with a commonly used melting furnace such as a converter furnace, an electric furnace or the like. Then, the molten steel is subjected to an ingot-making and blooming method or a continuous casting method so as to manufacture a bloom (a steel ingot) for rolling. Furthermore, the bloom is reheated to 1200°C or more, and then, the bloom is subjected to several passes of hot rolling, and molded into rails. Thereafter, heat treatments (reheating and cooling) are conducted so as to manufacture a rail.

In particular, in the hot metal step, general desulfurization and dephosphorization are conducted (dephosphorization and desulfurization treatment), and furthermore, sufficient desulfurization and dephosphorization are conducted in a commonly used melting furnace such as a converter furnace, an electric furnace or the like (dephosphorization and desulfurization treatment). Next, Ca is added to control Mn sulfide-based inclusions. Furthermore, according to necessity, Mg and Zr are added to finely disperse nano-sized oxides and Mn sulfide-based inclusions.

The details of the manufacturing conditions will be shown below.

[0067] In the hot metal step, it is preferable to conduct general dephosphorization treatment and desulfurization treatment in a careful manner to achieve the reduction of the amounts of P and S.

Regarding desulfurization, it is preferable to add CaO slowly and sufficiently in a hot-metal ladle (a preceding step of refining in a converter furnace), and to eject CaS as slag.

Meanwhile, the addition of CaO is a method conducted in the case where S is reduced from a hot metal having an extremely large amount of S. Unlike the addition of CaO-Si alloy, which is added to generate aggregates of oxides and sulfides of calcium (CaO-CaS), as described below, this method has no influence.

Regarding dephosphorization, it is preferable, in refining in a converter furnace, to eject slag in the middle of refining in order to prevent P from being melted again from the slag including P (P₂O₅ or the like) separated by dephosphorization.

[0068] Next, Ca is added so as to control Mn sulfide-based inclusions.

It is preferable to add Ca in a refining process prior to casting. A preferable adding method of Ca is either adding Ca alloy (Ca-Si alloy or the like) wires or Ca alloy ingots in a ladle or injecting a Ca alloy powder.

As the Ca alloy, a Ca-Si alloy (50Ca-50Si or the like), a Fe-Si-Ca alloy (Fe-30Si-30Ca or the like) and a Ni-Ca alloy (90Ni-10Ca or the like) are used. Since the vapor pressure of Ca is high, if pure Ca is added, splashing occurs in a molten steel, or slag on the surface of the molten steel is involved into the molten steel; and thereby, the purity of the molten steel is degraded. In addition, the yield rate becomes low. Consequently, the addition of a Ca alloy, for example, a Ca-Si alloy is widely conducted. Compared with pure Ca, the activity of Ca is lowered in the Ca alloy. Therefore, in the case of adding the Ca alloy, vaporization during the addition becomes relatively gentle, and the yield rate is also improved.

The lower the concentration of Ca in the alloy is, the more the yield rate is improved, and the generation of splashing during the addition is also suppressed. Therefore, the low concentration of Ca in the alloy is preferable. However, since elements other than Ca (Si or the like) are included in the case where the concentration of Ca is low, it is necessary to carefully select the composition of the Ca alloy.

[0069] In order to prevent the aggregation or segregation of the aggregates of the oxides and sulfides of calcium (CaO-CaS), it is preferable to stir the molten steel via Ar bubbling or the like in the ladle after the addition of the Ca alloy so as to make the concentration of Ca uniform and to float large-sized inclusions. In the case where an amount of the molten steel is 200 t or more, it is preferable to conduct the stirring for about 5 minutes to 10 minutes. Excessive stirring causes the aggregation of inclusions; and thereby, the inclusions coarsen. Therefore, excessive stirring is not preferable. From the viewpoint of ensuring the yield rate of Ca, it is advantageous to perform the addition of a Ca alloy at the final stage of a refining process. Ca may be added to a tundish in a casting process, instead of the refining process. It is necessary to adjust the addition rate of a Ca alloy depending on the throughput during casting (the casting amount per hour). In this case, since the stirring of the molten steel after the addition of Ca is conducted inside the tundish or a casting mold, the uniformity of the concentration of Ca is slightly worse than that in the case of adding Ca in the ladle. Therefore, it is preferable to stir the molten steel during solidification via an electromagnetic force or the like in order to prevent the aggregation or segregation of the aggregates of the oxides and sulfides of calcium (CaO-CaS) in the casting step. In addition, it is preferable to optimize the shape of a casting nozzle in order to control the flow of the molten steel during the casting.

Furthermore, in order to efficiently generate CaS having a high consistency with Mn sulfide-based inclusions, it is preferable to adjust the amount of oxygen in the molten steel so as to suppress the generation of an excessive amount of CaO. In order to adjust the amount of oxygen in advance, it is preferable to deoxidize the molten steel in advance via Al, Si or the like.

[0070] In addition, in order to finely disperse fine nano-sized oxides and Mn sulfide-based inclusions, it is preferable to add pure metallic Mg, an Mg alloy (Fe-Si-Mg, Fe-Mn-Mg, Fe-Si-Mn-Mg and Si-Mg) or a Zr alloy (Fe-Si-Zr, Fe-Mn-Mg-Zr and Fe-Si-Mn-Mg-Zr) in a molten-steel ladle at high temperatures after general refining or in a tundish during casting. Furthermore, it is preferable to stir the molten steel during solidification via an electromagnetic force or the like in order to prevent the aggregation or segregation in the casting step. In addition, it is preferable to optimize the shape of a casting nozzle in order to control the flow of the molten steel during the casting.

Here, although the order of adding Ca, Mg and Zr is not clearly described, in a high-carbon steel including a small amount of oxygen, it is preferable to add Ca having a relatively weak oxidizing power at first, and then to add Mg and Zr having strong oxidizing powers in order to generate oxides of Ca, Mg and Zr with a good efficiency.

[0071] In hot rolling, the temperature at which the final molding is conducted is preferably in a range of 900°C to 1000°C from the viewpoint of ensuring the shape and material.

In addition, regarding the heat treatment after the hot rolling, it is preferable to conduct accelerated cooling on a rail head portion 3 at high temperatures including austenite regions after hot rolling or reheating in order to obtain a pearlite structure with a hardness Hv of 320 to 500 in the rail head portion 3. As the accelerated cooling method, by conducting the heat treatment (and cooling) with a method described in Patent Document 8 (Japanese Unexamined Patent Application, Publication No. H08-246100), Patent Document 9 (Japanese Unexamined Patent Application, Publication No. H09-111352) or the like, it is possible to obtain a structure and hardness in predetermined ranges.

Here, in order to conduct the heat treatment with reheating after the rolling of the rail, it is preferable to heat the rail head portion or the entire rail with a flame or induction heating.

EXAMPLES

[0072] Next, examples of the present invention will be described.

Tables 1 to 6 show the chemical components of tested rail steels. Here, the balance consists of Fe and inevitable impurities. Rail steels having the component compositions shown in Tables 1 to 6 were manufactured in the following manner.

Dephosphorization and desulfurization were conducted in a hot metal step, and, furthermore, sufficient dephosphorization and desulfurization were conducted in a commonly used melting furnace such as a converter furnace, an electric furnace or the like so as to obtain molten steel. Ca was added to the molten steel so as to control Mn sulfide-based inclusions, or Mg and Zr were further added so as to finely disperse nano-sized oxides and Mn sulfide-based inclusions. Then, a steel ingot was manufactured by a continuous casting method, and hot rolling was conducted on the steel ingot. Thereafter, a heat treatment was conducted so as to manufacture a rail.

[0073]

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Table 1

Rail	Steel	Chemical components (mass %)								S/Ca
		C	Si	Mn	P	S	Ca	Mg, Zr	Co, Cr, Mo, V, Nb, B, Cu, Ni, Ti, Al, N	
Rail steels of the present invention	1	0.65	0.25	0.80	0.0100	0.0050	0.0020	Mg: 0.0020	Cu: 0.15	2.50
	2	1.20	0.25	0.80	0.0100	0.0050	0.0020	Mg: 0.0020	Cu: 0.15	2.50
	3	0.85	0.05	0.60	0.0120	0.0070	0.0080	-		0.88
	4	0.85	2.00	0.60	0.0120	0.0070	0.0080	-		0.88
	5	0.90	0.30	0.05	0.0060	0.0040	0.0060	Mg: 0.0020 Zr: 0.0012	Cr: 0.25	0.67
	6	0.90	0.30	2.00	0.0060	0.0040	0.0060	Mg: 0.0020 Zr: 0.0012	Cr: 0.25	0.67
	7	1.00	0.50	1.00	0.0150	0.0030	0.0100	-		0.30
	8	1.00	0.50	1.00	0.0020	0.0030	0.0100	-		0.30
	9	1.10	0.50	0.70	0.0150	0.0100	0.0120	Zr: 0.0015		0.83
	10	1.10	0.50	0.70	0.0020	0.0010	0.0120	Zr: 0.0015		0.08
	11	0.95	0.95	0.80	0.0070	0.0030	0.0005	-	Ti: 0.01	6.00
	12	0.95	0.95	0.80	0.0070	0.0030	0.0200	-	Ti: 0.01	0.15

[0074]

Table 2

Rail	Steel	Chemical components (mass %)								S/Ca
		C	Si	Mn	P	S	Ca	Mg, Zr	Co, Cr, Mo, V, Nb, B, Cu, Ni, Ti, Al, N	
Rail steels of the present invention	13	0.65	0.30	0.75	0.0080	0.0050	0.0190	-		0.26
	14	0.65	0.30	0.75	0.0080	0.0050	0.0035	-		1.43
	15	0.65	0.30	0.75	0.0080	0.0050	0.0035	Mg: 0.0012 Zr: 0.0015		1.43
	16	0.70	0.30	0.75	0.0040	0.0060	0.0020	Zr: 0.0020		3.00
	17	0.70	1.25	0.20	0.0140	0.0020	0.0040	-	Ni: 0.25	0.50
	18	0.75	0.50	1.00	0.0130	0.0060	0.0008	-	Nb: 0.01	7.50
	19	0.75	0.50	1.00	0.0130	0.0060	0.0080	-	Nb: 0.01	0.75
	20	0.75	0.50	1.00	0.0130	0.0060	0.0080	Mg: 0.0050	Nb: 0.01	0.75
	21	0.80	0.40	1.10	0.0100	0.0100	0.0020	-		5.00
	22	0.80	0.40	1.10	0.0100	0.0060	0.0020	-		3.00
	23	0.80	0.40	1.10	0.0100	0.0020	0.0020	-		1.00
	24	0.85	0.55	0.85	0.0060	0.0080	0.0009	-		8.89

[0075]

Table 3

Rail	Steel	Chemical components (mass %)								S/Ca
		C	Si	Mn	P	S	Ca	Mg, Zr	Co, Cr, Mo, V, Nb, B, Cu, Ni, Ti, Al, N	
Rail steels of the present invention	25	0.85	0.55	0.85	0.0060	0.0080	0.0050	-		1.60
	26	0.85	0.55	0.85	0.0060	0.0080	0.0050	Mg: 0.0040 Zr: 0.0025		1.60
	27	0.90	0.30	1.25	0.0050	0.0095	0.0140	Zr: 0.0050		0.68
	28	0.90	0.30	1.25	0.0050	0.0095	0.0140	Zr: 0.0050	Co: 0.30	0.68
	29	0.95	0.95	0.80	0.0070	0.0030	0.0005	-	Ti:0.01	6.00
	30	0.95	0.95	0.80	0.0070	0.0030	0.0030	-	Ti: 0.01	1.00
	31	0.95	0.95	0.80	0.0070	0.0030	0.0030	Mg: 0.0020 Zr:0.0030	Ti: 0.01	1.00
	32	0.95	0.25	1.20	0.0095	0.0095	0.0150	-	Mo:0.02	0.63
	33	1.00	0.50	0.70	0.0040	0.0080	0.0009	-	Cr:0.20	8.89
	34	1.00	0.50	0.70	0.0040	0.0080	0.0045	-	Cr:0.20	1.78
	35	1.00	0.50	0.70	0.0040	0.0080	0.0045	Mg: 0.0050	Cr:0.20	1.78
	36	1.05	0.10	0.90	0.0050	0.0025	0.0160	-	Al: 0.0080	0.16

[0076]

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Table 4

Rail	Steel	Chemical components (mass %)								S/Ca
		C	Si	Mn	P	S	Ca	Mg, Zr	Co, Cr, Mo, V, Nb, B, Cu, Ni, Ti, Al, N	
Rail steels of the present invention	37	1.05	0.10	0.90	0.0050	0.0025	0.0030	-	Al: 0.0080	0.83
	38	1.05	0.10	0.90	0.0050	0.0025	0.0030	Mg: 0.0050 Zr: 0.0010	Al: 0.0080	0.83
	39	1.05	0.85	0.80	0.0030	0.0040	0.0050	Mg: 0.0007	B: 0.0020, Ti: 0.01	0.80
	40	1.10	0.50	0.70	0.0040	0.0050	0.0040	Mg: 0.0005 Zr: 0.0005		1.25
	41	1.10	0.50	0.70	0.0040	0.0050	0.0040	Mg: 0.0020 Zr: 0.0020		1.25
	42	1.10	0.50	0.70	0.0040	0.0050	0.0040	Mg: 0.0080 Zr: 0.0080		1.25
	43	1.15	0.35	1.35	0.0040	0.0070	0.0040	-		1.75
	44	1.15	0.95	0.90	0.0050	0.0090	0.0020	Mg: 0.0020	V: 0.02	4.50
	45	1.20	1.25	0.45	0.0020	0.0060	0.0010	-	N: 0.0080	6.00
	46	1.20	1.25	0.45	0.0020	0.0060	0.0035	-	N: 0.0080	1.71
	47	1.20	1.25	0.45	0.0020	0.0060	0.0035	Mg: 0.0010 Zr: 0.0030	N: 0.0080	1.71

[0077]

Table 5

Rail	Steel	Chemical components (mass %)								S/Ca
		C	Si	Mn	P	S	Ca	Mg, Zr	Co, Cr, Mo, V, Nb, B, Cu, Ni, Ti, Al, N	
Comparative rail steels	48	<u>0.60</u>	0.25	0.80	0.0100	0.0050	0.0020	Mg: 0.0020	Cu: 0.15	2.50
	49	<u>1.30</u>	0.25	0.80	0.0100	0.0050	0.0020	Mg: 0.0020	Cu: 0.15	2.50
	50	0.85	<u>0.01</u>	0.60	0.0120	0.0070	0.0080	-		0.88
	51	0.85	<u>2.50</u>	0.60	0.0120	0.0070	0.0080	-		0.88
	52	0.90	0.30	0.01	0.0060	0.0040	0.0060	Mg: 0.0020 Zr: 0.0012	Cr: 0.25	0.67
	53	0.90	0.30	<u>2.30</u>	0.0060	0.0040	0.0060	Mg: 0.0020 Zr: 0.0012	Cr: 0.25	0.67
	54	1.00	0.50	1.00	<u>0.0250</u>	0.0030	0.0100	-		0.30
	55	1.10	0.50	0.70	0.0150	<u>0.0240</u>	0.0120	Zr: 0.0015		2.00
	56	0.95	0.95	0.80	0.0070	0.0030	<u>0.0001</u>	-	Ti: 0.01	30.00
	57	0.95	0.95	0.80	0.0070	0.0030	<u>0.0300</u>	-	Ti: 0.01	0.10
	58	0.65	0.30	0.75	<u>0.0160</u>	0.0050	0.0035	-		1.43

[0078]

Table 6

Rail	Steel	Chemical components (mass %)								S/Ca
		C	Si	Mn	P	S	Ca	Mg, Zr	Co, Cr, Mo, V, Nb, B, Cu, Ni, Ti, Al, N	
Comparative rail steels	59	0.75	0.50	1.00	<u>0.0180</u>	<u>0.0150</u>	<u>0.0004</u>	-	Nb: 0.01	37.50
	60	0.85	0.55	0.85	0.0060	<u>0.0120</u>	0.0050	-		2.40
	61	0.95	0.95	0.80	<u>0.0170</u>	0.0030	<u>0.0002</u>	-	Ti: 0.01	15.0
	62	1.05	0.10	0.90	0.0050	0.0025	<u>0.0210</u>	-	Al: 0.0080	0.12
	63	1.20	1.25	0.45	<u>0.0190</u>	<u>0.0130</u>	0.0035	-	N: 0.0090	3.71
	64	0.65	0.30	0.45	0.0080	0.0050	0.0010	-		5.00
	65	1.20	0.50	0.45	0.0020	0.0060	0.0050	-	N: 0.0080	1.20
	66	0.95	1.20	1.20	0.0070	0.0030	0.0080	-	Ti: 0.01	0.38
	67	0.85	0.30	0.30	0.0060	0.0080	0.0025	-		3.20
	68	1.05	1.00	1.35	0.0050	0.0025	0.0030	-	Al: 0.0080	0.83

(a) The measurement of the number of Mn sulfide-based inclusions

[0079] FIG. 3 shows a location at which Mn sulfide-based inclusions were observed in the rail steel which are defined in Claim 1.

As shown in FIG. 3, among cross-sections taken along the lengthwise direction of the obtained rail steel, a sample was cut off from a portion ranging from the surface of the rail head portion to a depth of 3 to 10 mm including the head surface portion 3a. Then, the number (per unit area) (inclusions/mm²) of Mn sulfide-based inclusions having major lengths (lengths of major axes) in a range of 10 μm to 100 μm was obtained by the above-described method.

(b) The measurement of the number of Mn sulfide-based inclusions, Mg-based oxides and Zr oxides

[0080] FIG. 4 shows a location at which Mn sulfide-based inclusions, Mg-based oxides and Zr oxides were observed in the rail steel which are defined in Claim 2.

As shown in FIG. 4, among transverse cross-sections of the obtained rail steel, a sample was cut off from a portion ranging from the surface of the rail head portion to a depth of 3 to 10 mm including the head surface portion 3a. Then, the number (per unit area) (inclusions/mm²) of Mg-based oxides, Zr oxides and Mn sulfide-based inclusions having grain diameters in a range of 5 nm to 100 nm was obtained by the above-described method.

(c) The observation of the microstructure and the measurement of the hardness of the head surface portion 3a

[0081] A sample was cut off from a portion situated at a depth of 4 mm from the surface of the rail head portion 3. Thereafter, a surface to be observed was polished, and then the surface was etched with nital etching fluid. The microstructure in the surface to be observed was observed using an optical microscope in accordance with JIS G 0551. In addition, in accordance with JIS B7774, the Vickers hardness Hv of the cut-off sample was measured. Here, the Vickers hardness was measured while a diamond indenter was loaded on the sample at a load of 98 N (10 kgf). The Vickers hardness is expressed as (Hv, 98N) in Tables.

The obtained results are shown in Tables 7 to 12. Here, in Tables, the 'Head portion material *1' refers to a material in a portion situated at a depth of 4 mm from the surface of the rail head portion 5.

[0082]

Table 7

Rail	Steel	Number of Mn sulfide-based inclusions having major lengths in a range of 10 μm to 100 μm (/mm ²)	Number of Mg-based oxides, Zr oxides and Mn sulfide-based inclusions having grain diameters in a range of 5 nm to 100 nm (/mm ²)	Head portion material *1	
				Microstructure	Hardness (Hv, 98N)
Rail steels of the present invention	1	50	3800	Pearlite + small amount of proeutectoid ferrite	320
	2	50	3800	Pearlite + small amount of proeutectoid cementite	400
	3	100	-	Pearlite	330
	4	100	-	Pearlite + small amount of martensite	460
	5	70	5600	Pearlite	320
	6	70	5600	Pearlite + small amount of martensite	460
	7	30	-	Pearlite	440
	8	30	-	Pearlite	440
	9	150	3500	Pearlite	420
	10	30	3500	Pearlite	420
	11	200	-	Pearlite	430
	12	10	-	Pearlite	430

[0083]

Table 8

Rail	Steel	Number of Mn sulfide-based inclusions having major lengths in a range of 10 μm to 100 $\mu\text{m}/(\text{mm}^2)$	Number of Mg-based oxides, Zr oxides and Mn sulfide-based inclusions having grain diameters in a range of 5 nm to 100 nm $(/\text{mm}^2)$	Head portion material * 1	
				Microstructure	Hardness (Hv, 98N)
Rail steels of the present invention	13	15	-	Pearlite	350
	14	70	-	Pearlite	350
	15	60	6800	Pearlite	350
	16	100	4000	Pearlite	350
	17	12	-	Pearlite	370
	18	190	-	Pearlite + small amount of bainite	390
	19	90	-	Pearlite + small amount of bainite	390
	20	80	17000	Pearlite + small amount of bainite	390
	21	180	-	Pearlite	400
	22	100	-	Pearlite	400
	23	20	-	Pearlite	400
	24	180	-	Pearlite	400

[0084]

Table 9

Rail	Steel	Number of Mn sulfide-based inclusions having major lengths in a range of 10 μm to 100 μm (/mm ²)	Number of Mg-based oxides, Zr oxides and Mn sulfide-based diameters in a range of 5 nm to 100 nm (/mm ²)	Head portion material * 1	
				Microstructure	Hardness (Hv, 98N)
Rail steels of the present invention	25	140	-	Pearlite	400
	26	130	30000	Pearlite	400
	27	170	18000	Pearlite	420
	28	170	19000	Pearlite	420
	29	190	-	Pearlite	430
	30	140	-	Pearlite	430
	31	130	19000	Pearlite	430
	32	170	-	Pearlite + small amount of martensite	450
	33	195	-	Pearlite	425
	34	150	-	Pearlite	425
	35	130	15000	Pearlite	425
	36	18	-	Pearlite	375

[0085]

Table 10

Rail	Steel	Number of Mn sulfide-based inclusions having major lengths in a range of 10 μm to 100 μm (/mm ²)	Number of Mg-based oxides, Zr oxides and Mn sulfide-based inclusions having grain diameters in a range of 5 nm to 100 nm (/mm ²)	Head portion material * 1	
				Microstructure	Hardness (Hv, 98N)
Rail steels of the present invention	37	100	-	Pearlite	375
	38	80	26000	Pearlite	375
	39	60	635	Pearlite	460
	40	90	1200	Pearlite	445
	41	80	13000	Pearlite	445
	42	50	45000	Pearlite	445
	43	120	-	Pearlite + small amount of proeutectoid cementite	500
	44	150	4500	Pearlite	450
	45	190	-	Pearlite + small amount of proeutectoid cementite	445
	46	90	-	Pearlite + small amount of proeutectoid cementite	445
	47	70	12000	Pearlite + small amount of proeutectoid cementite	445

[0086]

Table 11

Rail	Steel	Number of Mn sulfide-based inclusions having major lengths in a range of 10 μm to 100 μm (/mm ²)	Number of Mg-based oxides, Zr oxides and Mn sulfide-based inclusions having grain diameters in a range of 5 nm to 100 nm (/mm ²)	Head portion material *1	
				Microstructure	Hardness (H 98N)
Comparative rail steels	48	50	3800	<u>Pearlite + proeutectoid ferrite</u>	<u>300</u>
	49	50	3800	<u>Pearlite + proeutectoid cementite</u>	420
	50	100	-	Pearlite	<u>310</u>
	51	100	-	<u>Pearlite + martensite</u>	550
	52	70	5600	Pearlite	<u>280</u>
	53	70	5600	<u>Pearlite + martensite</u>	<u>580</u>
	54	30	-	Pearlite	440
	55	<u>300</u> (number of inclusions increase → toughness decreases)	-	Pearlite	420
	56	<u>230</u> (number of inclusions increase → toughness decreases)	-	Pearlite	430
	57	<u>5</u> (CaO generates → toughness decreases)	-	Pearlite	430
	58	70	-	Pearlite	350

[0087]

Table 12

Rail	Steel	Number of Mn sulfide-based inclusions having major lengths in a range of 10 μm to 100 μm (/mm ²)	Number of Mg-based oxides, Zr oxides and Mn sulfide-based inclusions having grain diameter in a range of 5 nm to 100 nm (/mm ²)	Head portion material *1 1	
				Microstructure	Hardness (Hv, 98N)
Comparative rail steels	59	<u>220</u> (number of inclusions increase $\rightarrow$ toughness decreases)	-	Pearlite + small amount of bainite	390
	60	140	-	Pearlite	400
	61	<u>210</u> (number of inclusions increase $\rightarrow$ toughness decreases)	-	Pearlite	430
	62	<u>8</u> (CaO generates $\rightarrow$ toughness decreases)	-	Pearlite	375
	63	90	-	Pearlite + small amount of proeutectoid cementite	445
	64	70	-	<u>Pearlite + proeutectoid ferrite</u>	320
	65	90	-	<u>Pearlite + proeutectoid cementite</u>	370
	66	140	-	<u>Pearlite + martensite</u>	490
	67	140	-	Pearlite	<u>300</u>
	68	100	-	Pearlite	<u>520</u>

(d) Wear test

[0088] FIG. 5 shows a location from which a test specimen for the wear test was taken, and the numeric values in the drawing show dimensions (mm).

As shown in FIG. 5, a disk-like test specimen was cut off from a portion including the head surface portion 3a in the rail steel. Then, as shown in FIG. 6, two opposing rotation axes were prepared, the disk-like test specimen (rail test specimen 4) was disposed at one of the rotation axis, and an opponent material 5 was disposed at the other rotation axis. The rail test specimen 4 and the opponent material 5 were brought into contact in a state where a predetermined load was applied to the rail test specimen 4. In such a state, the two rotation axes were rotated at a predetermined speed while cooling the test specimen by supplying a compressed air from a cooling nozzle 6. Then, after rotating the axes 700,000 times, the reduced amount (abraded amount) of the weight of the rail test specimen 4 was measured.

The conditions for the wear test are shown below.

Testing machine: Nishihara-type wear testing machine (refer to FIG. 6)

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Shape of test specimen: Disk-like test specimen (outer diameter: 30 mm, thickness: 8 mm)

Location from which the test specimen is taken: 2 mm below the surface of the rail head portion (refer to FIG. 5)

Test load: 686 N (contact surface pressure 640 MPa)

Sliding ratio: 20 %

5 Opponent material: pearlite steel (Hv 380)

Atmosphere: in the atmosphere (air)

Cooling: Forcible cooling by a compressed air (flow rate: 100 Nl/min)

Number of repetitions: 700,000

10 (e) Impact test of the head portion

[0089] FIG. 7 shows a location from which a test specimen for the impact test was taken.

As shown in FIG 7, a test specimen was cut off along the rail width direction (transverse cross-section) in the transverse cross-section of the rail steel so that a portion including the head surface portion 3a forms the bottom of a notch. Then, the obtained test specimen was subjected to an impact test under the following conditions; and thereby, impact values (J/cm²) were measured.

Testing machine: Impact testing machine

Shape of test specimen: 2 mm U notch in JIS No. 3

Location from which the test specimen is taken: 2 mm below the surface of the rail head portion (refer to FIG 7)

20 Testing temperature: normal temperature (20°C)

[0090] The obtained results are shown in Tables 13 to 15. Here, in Tables, the 'Wear test results *2' refer to the results of the above-described wear test, and the reduced amount (g) of the weight of the rail test specimen 13 is expressed as the abraded amount. The 'Impact test results *3' refer to the results of the above-described impact test of the head portion and show impact values (J/cm²). Meanwhile, a larger impact value (J/cm²) means a more superior toughness.

25 In the present evaluation, a case where an abraded amount was in a range of 1.5 g or less after the 700,000 times rotation was evaluated to have an excellent wear resistance. Since the impact values measured at 20°C are greatly varied with the amount of carbon in the steel, criterion values which showed the relative merits of characteristics were not set, and the relative merits of the impact values were evaluated among the rail steels having the same amount of carbon.

30 **[0091]**

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Table 13

Rail	Steel	Wear test results *2 (g, 700,000 times)	Impact test results *3
			Impact value (J/cm ²)
Rail steels of the present invention	1	1.45	37.0
	2	0.35	10.0
	3	1.25	19.0
	4	1.10	17.0
	5	1.00	16.0
	6	0.91	14.5
	7	0.62	12.5
	8	0.63	16.0
	9	0.46	11.3
	10	0.45	13.0
	11	0.80	13.0
	12	0.81	12.0
	13	1.35	33.0
	14	1.33	34.5
	15	1.37	38.5
	16	1.25	29.0
	17	1.22	26.0
	18	1.18	25.0
	19	1.19	27.0
	20	1.18	31.0
	21	1.05	18.5
	22	1.04	19.5
	23	1.06	22.5
	24	0.95	19.5

[0092]

Table 14

Rail	Steel	Wear test results *2 (g, 700,000 times)	Impact test results *3
			Impact value (J/cm ²)
Rail steels of the present invention	25	0.94	20.5
	26	0.94	25.0
	27	0.86	18.0
	28	0.70	18.5
	29	0.75	14.0
	30	0.74	15.5
	31	0.75	18.5
	32	0.72	14.2
	33	0.60	12.5
	34	0.62	14.0
	35	0.60	16.0
	36	0.64	12.0
	37	0.63	13.5
	38	0.63	16.0
	39	0.45	13.5
	40	0.44	12.5
	41	0.43	14.0
	42	0.44	16.0
	43	0.30	11.0
	44	0.32	12.0
	45	0.25	10.0
	46	0.26	11.5
	47	0.27	14.0

[0093]

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Table 15

Rail	Steel	Wear test results *2 (g, 700,000 times)	Impact test results *3
			Impact value (J/cm ²)
Comparative rail steels	48	<u>2.30 (greatly abraded)</u>	37.0
	49	0.30	<u>5.0 (impact value is lowered)</u>
	50	<u>1.65 (greatly abraded)</u>	18.0
	51	<u>1.80 (greatly abraded)</u>	<u>4.5 (impact value is lowered)</u>
	52	<u>1.62 (greatly abraded)</u>	16.0
	53	<u>1.90 (greatly abraded)</u>	<u>4.0 (impact value is lowered)</u>
	54	0.62	9.0
	55	0.46	7.5
	56	0.75	9.5
	57	0.75	8.0
	58	1.35	29.0
	59	1.18	20.0
	60	0.95	14.0
	61	0.75	9.8
	62	0.64	9.0
	63	0.25	7.0
	64	<u>2.00 (greatly abraded)</u>	35.0
	65	0.40	<u>6.0 (impact value is lowered)</u>
	66	<u>1.90 (greatly abraded)</u>	<u>4.0 (impact value is lowered)</u>
	67	<u>1.75 (greatly abraded)</u>	18.0
	68	0.40	<u>7.0 (impact value is lowered)</u>

[0094] (1) Rails according to the present invention (47 rails), Steel Nos. 1 to 47

Steel Nos. 3, 4, 7, 8, 11 to 14, 17 to 19, 21 to 25, 29, 30, 32 to 34, 36, 37, 43, 45 and 46: pearlite rails having superior wear resistance and toughness which have the chemical compositions within the above-described limited range of the present invention and of which the number of Mn sulfide-based inclusions having major lengths (lengths of major axes) in a range of 10 μm to 100 μm , the microstructure of the rail head portion and the hardness are within the limited ranges of the present invention.

Steel Nos. 1, 2, 5, 6, 9, 10, 15, 16, 20, 26 to 28, 31, 35, 38 to 42, 44 and 47: pearlite rails having superior wear resistance and toughness which have the chemical compositions within the above-described limited range of the present invention and of which the number of Mn sulfide-based inclusions having major lengths (lengths of major axes) in a range of 10 μm to 100 μm , the number of Mg-based oxides, Zr oxides and Mn sulfide-based inclusions having grain diameters in a range of 5 nm to 100 nm, the microstructure of the rail head portion and the hardness are within the limited ranges of the present invention.

[0095] (2) Comparative rails (21 rails), Steel Nos. 48 to 68

Steel Nos. 48 to 53: rails of which the amounts of C, Si and Mn are outside the ranges of the present invention.

Steel Nos. 54 to 55: rails of which the amounts of P and S are outside the ranges of the present invention.

Steel Nos. 56 to 57: rails of which the amount of Ca is outside the range of the present invention.

Steel Nos. 58 to 63: rails of which the amounts of P, S and Ca are outside the range of the present invention.

Steel Nos. 64 to 66: rails of which the chemical compositions are within the range of the present invention; however, the microstructure of the head portion does not fulfill the above-described features of the present invention.

Steel Nos. 67 to 68: rails of which the chemical compositions are within the range of the present invention; however, the hardness of the head portion is outside the above-described range of the present invention.

[0096] As shown in Tables 1 to 15, compared with the comparative rail steels (Steel Nos. 48 to 53), the rail steels

according to the present invention (Steel Nos. 1 to 47) include C, Si and Mn at contents within the limited ranges of the present invention. Therefore, it is possible to stably obtain a pearlite structure having a hardness within the limited range of the present invention without generating eutectoid ferrite structure, eutectoid cementite structure and martensite structure, which adversely affect the wear resistance and the toughness.

Compared with the comparative rail steels (Steel Nos. 64 to 68), the rail steels according to the present invention (Steel Nos. 1 to 47) include a pearlite structure in the microstructure of the head portion, and the hardness of the pearlite structure is within the limited range of the present invention. As a result, it is possible to improve the wear resistance and the toughness of the rail.

[0097] FIG. 8 shows the results of the wear test of the rail steels according to the present invention (Steel Nos. 1 to 47) and Comparative rail steels (Steel Nos. 48, 50, 51, 52, 53, 64, 66 and 67).

In the case where C, Si and Mn are included at amounts within the limited range of the present invention, the generation of eutectoid ferrite structure and martensite structure, which adversely affect the wear resistance, is prevented, and in addition, the hardness is within the limited range of the present invention. Thereby, it is possible to greatly improve the wear resistance with any amount of carbon.

[0098] FIG. 9 shows the results of the impact test of the rail steels according to the present invention (Steel Nos. 1 to 47) and Comparative rail steels (Steel Nos. 49, 51, 53, 65, 66 and 68).

In the case where C, Si and Mn are included at amounts within the limited range of the present invention, the generation of eutectoid cementite structure and martensite structure, which adversely affect the toughness, is prevented, and in addition, the hardness is within the limited range of the present invention. Thereby, it is possible to greatly improve the toughness with any amount of carbon.

[0099] As shown in FIG. 10, compared with the comparative rail steels (Steel Nos. 54 to 63), the rail steels according to the present invention (Steel Nos. 1 to 47) include P, S and Ca at amounts within the limited ranges of the present invention. Thereby, it is possible to greatly improve the toughness of the pearlite rails with any amount of carbon.

Furthermore, as shown in FIG 11, the rail steels according to the present invention (Steel Nos. 11 to 13, 18 to 20, 24 to 26, 29 to 31, 33 to 35, 36 to 38 and 45 to 47) include Ca, and furthermore, the added amount of Ca is optimized. Thereby, Mn sulfide-based inclusions are controlled so that the number thereof is within the limited range of the present invention.

As a result, it is possible to improve the toughness of the pearlite rail. In addition, in the case where Mg and Zr are added, oxides and Mn sulfide-based inclusions are finely dispersed so that the number of Mg-based oxides, Zr oxides and Mn sulfide-based inclusions is made to be in a range of 500/mm² to 50,000/mm². Thereby, it is possible to further improve the toughness of the pearlite rail.

INDUSTRIAL APPLICABILITY

[0100] The pearlite rail according to the present invention has wear resistance and toughness superior to those of a high-strength rail in current use. Therefore, the present invention can be preferably applied to rails used in an extremely severe track environment, such as rails for freight railways that transport natural resources mined from regions with severe natural environments.

Brief Description of Symbols

[0101]

- 1: head top portion
- 2: head corner portion
- 3: rail head portion
- 3a: head surface portion
- 3b: a portion ranging from surfaces of head corner portions and a head top portion to a depth of 20 mm
- 4: rail test specimen
- 5: opposing material
- 6: nozzle for cooling

Claims

1. A pearlite rail consisting of a steel comprising: in terms of percent by mass,
C: 0.65 to 1.20%;
Si: 0.05 to 2.00%;
Mn: 0.05 to 2.00%;

P ≤ 0.0150%;

S ≤ 0.0100%;

Ca: 0.0005 to 0.0200%; and

Fe and inevitable impurities as the balance,

wherein, in a head portion of the rail, a head surface portion which ranges from surfaces of head corner portions and a head top portion to a depth of 10 mm has a pearlite structure,

a hardness Hv of the pearlite structure is in a range of 320 to 500, and

Mn sulfide-based inclusions having major lengths in a range of 10 to 100 μm are present at an amount per unit area in a range of 10 to 200/mm² in a cross-section taken along a lengthwise direction in the pearlite structure.

2. The pearlite rail according to Claim 1, wherein the steel further comprises, in terms of percent by mass, either one or both of Mg: 0.0005 to 0.0200% and Zr: 0.0005 to 0.0100%, and Mg-based oxides, Zr oxides, and Mn sulfide-based inclusions having grain diameters in a range of 5 nm to 100 nm are present at an amount per unit area in a range of 500 to 50,000/mm² in a transverse cross-section in the pearlite structure.

3. The pearlite rail according to Claim 1 or 2, wherein the steel further comprises, in terms of percent by mass, Co: 0.01 % to 1.00%.

4. The pearlite rail according to any one of Claims 1 to 3, wherein the steel further comprises, in terms of percent by mass, either one or both of Cr: 0.01 to 2.00% and Mo: 0.01 to 0.50%.

5. The pearlite rail according to any one of Claims 1 to 4, wherein the steel further comprises, in terms of percent by mass, either one or both of V: 0.005 to 0.50% and Nb: 0.002 to 0.050%.

6. The pearlite rail according to any one of Claims 1 to 5, wherein the steel further comprises, in terms of percent by mass, B: 0.0001 to 0.0050%.

7. The pearlite rail according to any one of Claims 1 to 6, wherein the steel further comprises, in terms of percent by mass, Cu: 0.01 to 1.00%.

8. The pearlite rail according to any one of Claims 1 to 7, wherein the steel further comprises, in terms of percent by mass, Ni: 0.01 to 1.00%.

9. The pearlite rail according to any one of Claims 1 to 8, wherein the steel further comprises, in terms of percent by mass, Ti: 0.0050 to 0.0500%.

10. The pearlite rail according to any one of Claims 1 to 9, wherein the steel further comprises, in terms of percent by mass, Al: more than 0.0100 to 1.00%.

11. The pearlite rail according to any one of Claims 1 to 10, wherein the steel further comprises, in terms of percent by mass, N: 0.0060 to 0.0200%.

FIG. 1

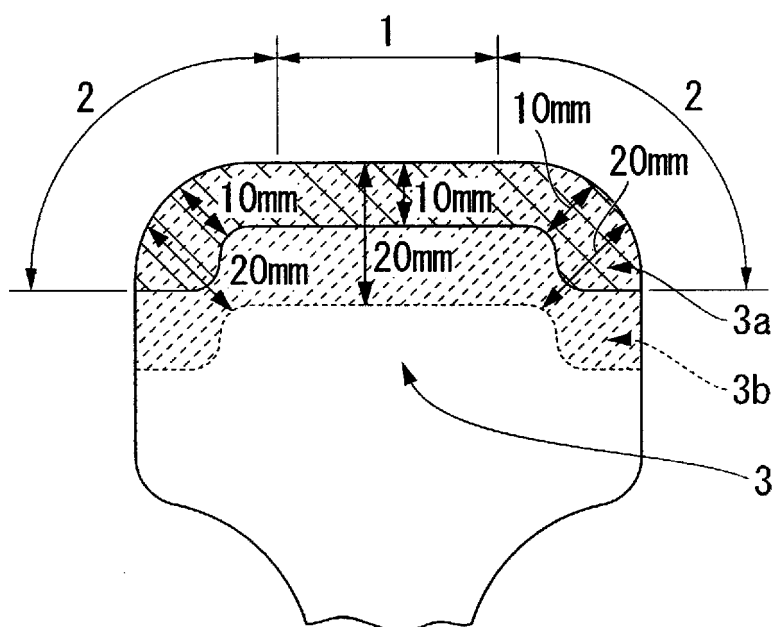


FIG. 2

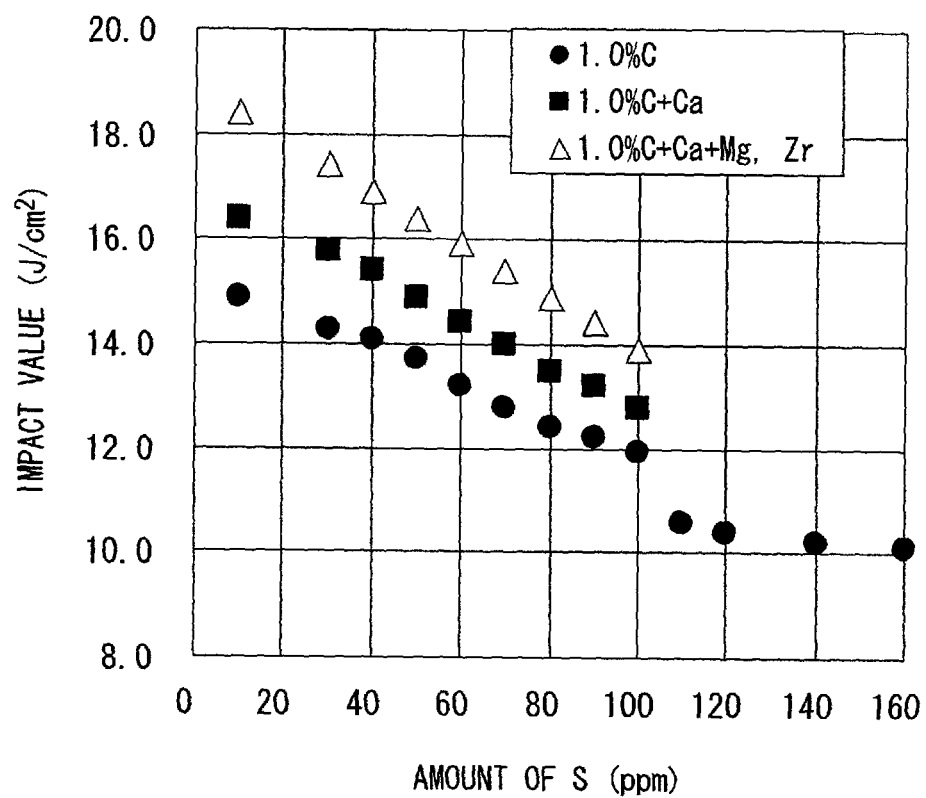


FIG. 3

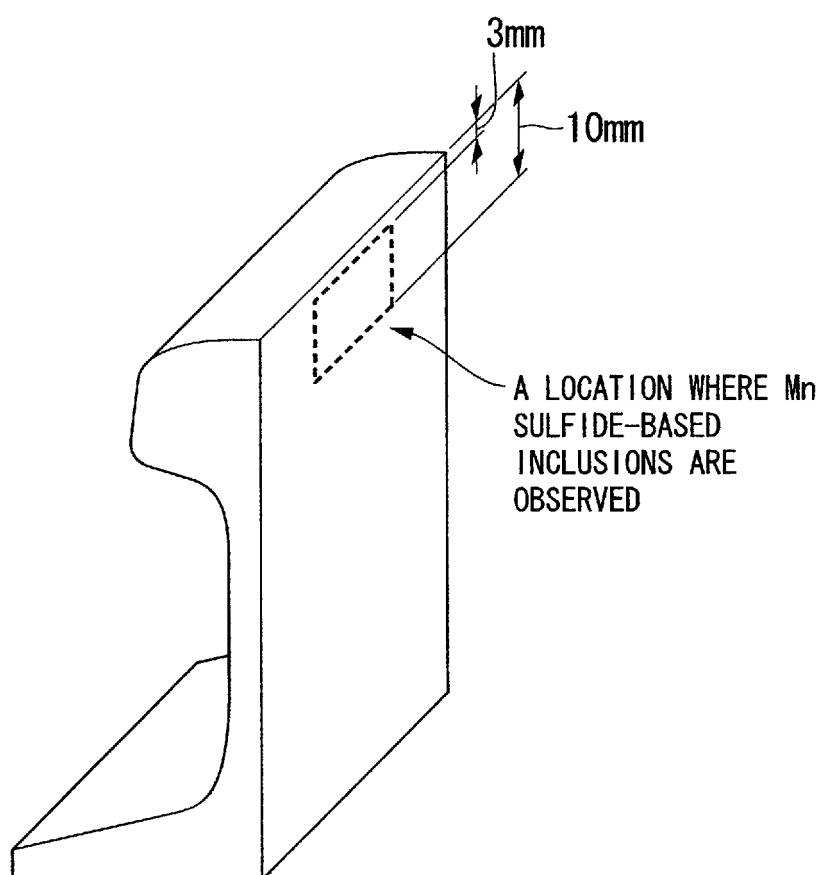


FIG. 4

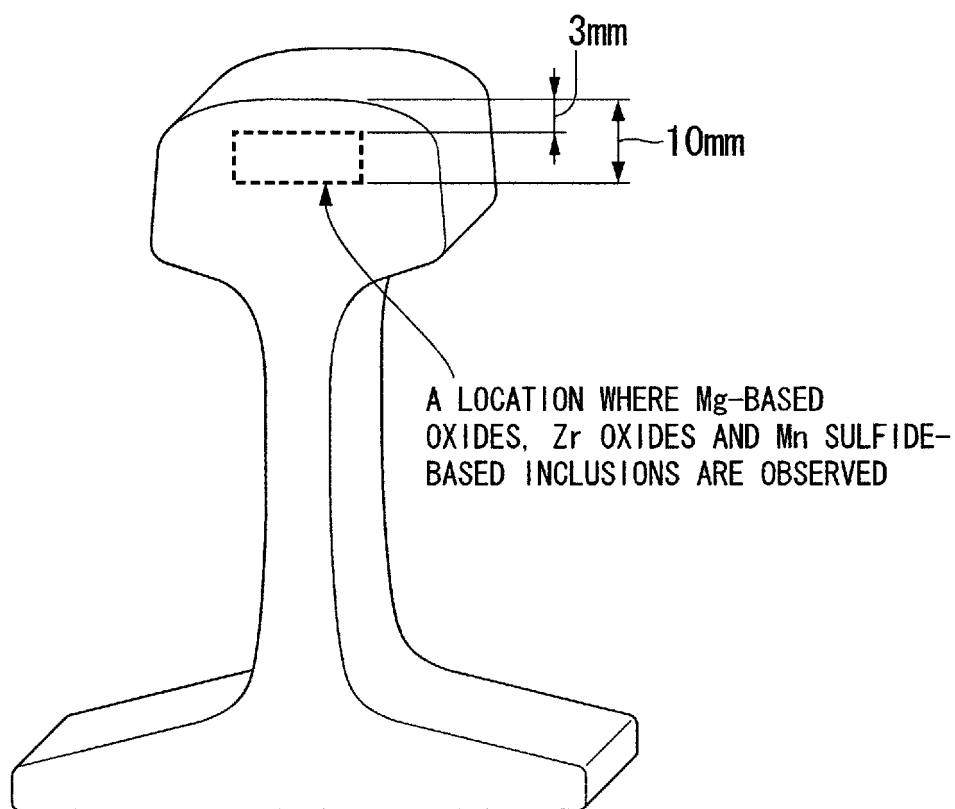


FIG. 5

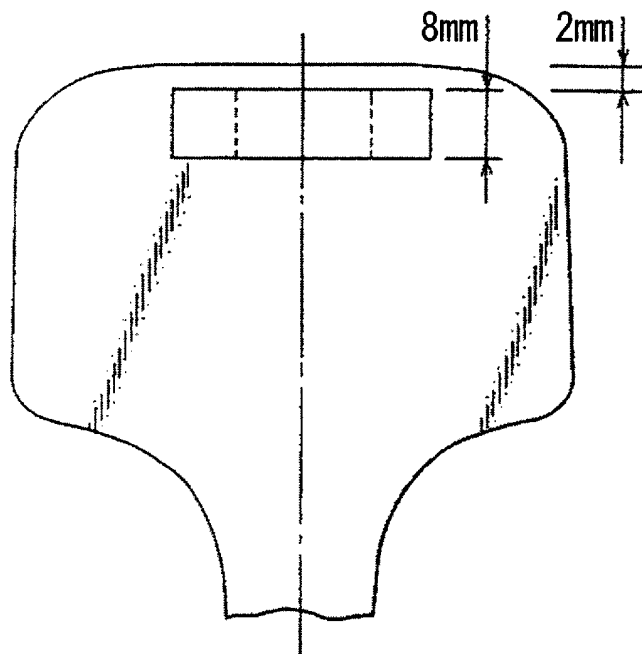


FIG. 6

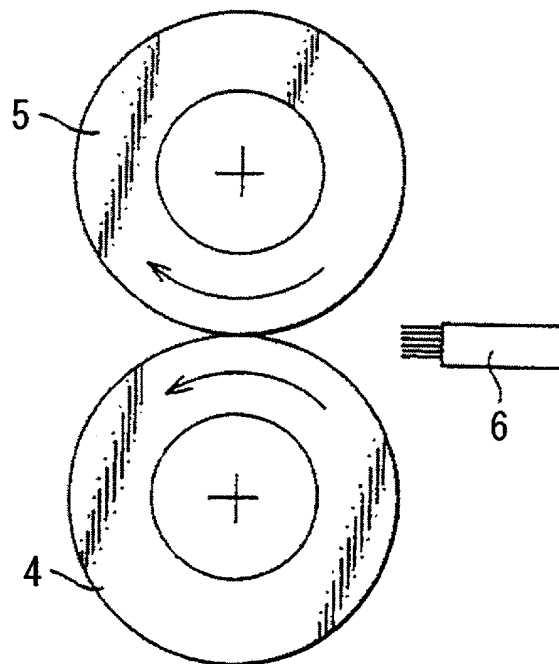


FIG. 7

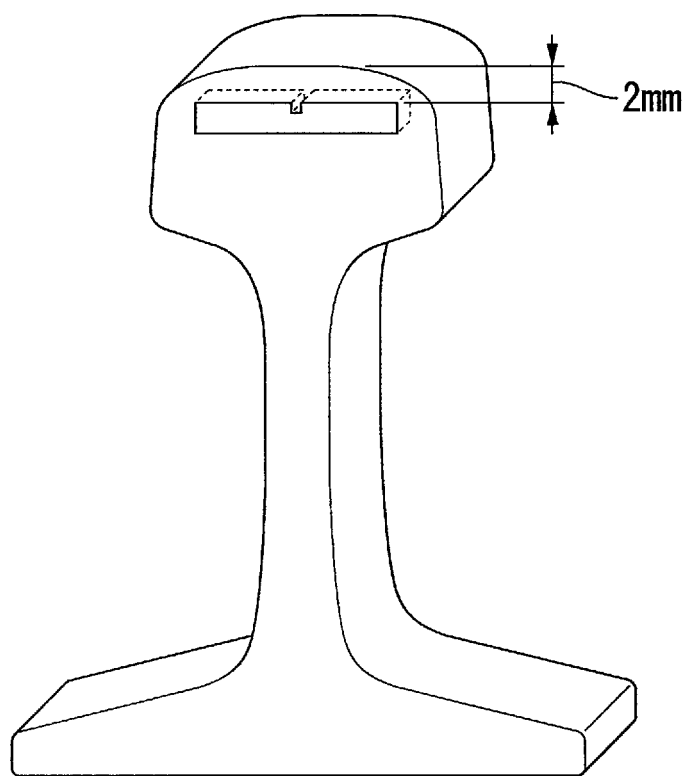


FIG. 8

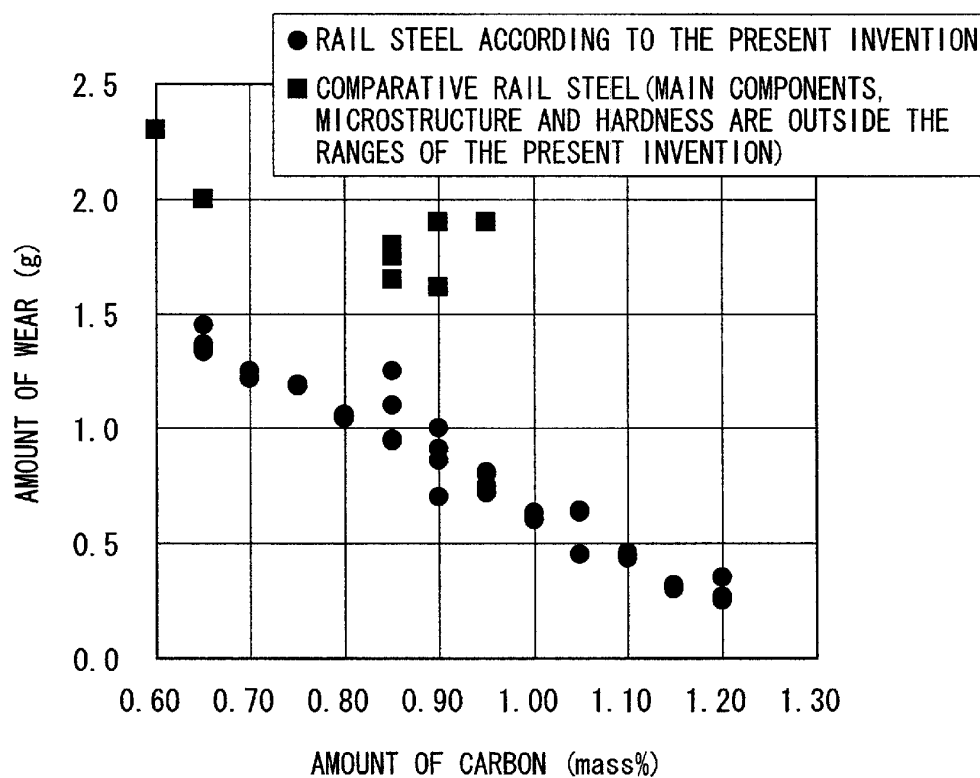


FIG. 9

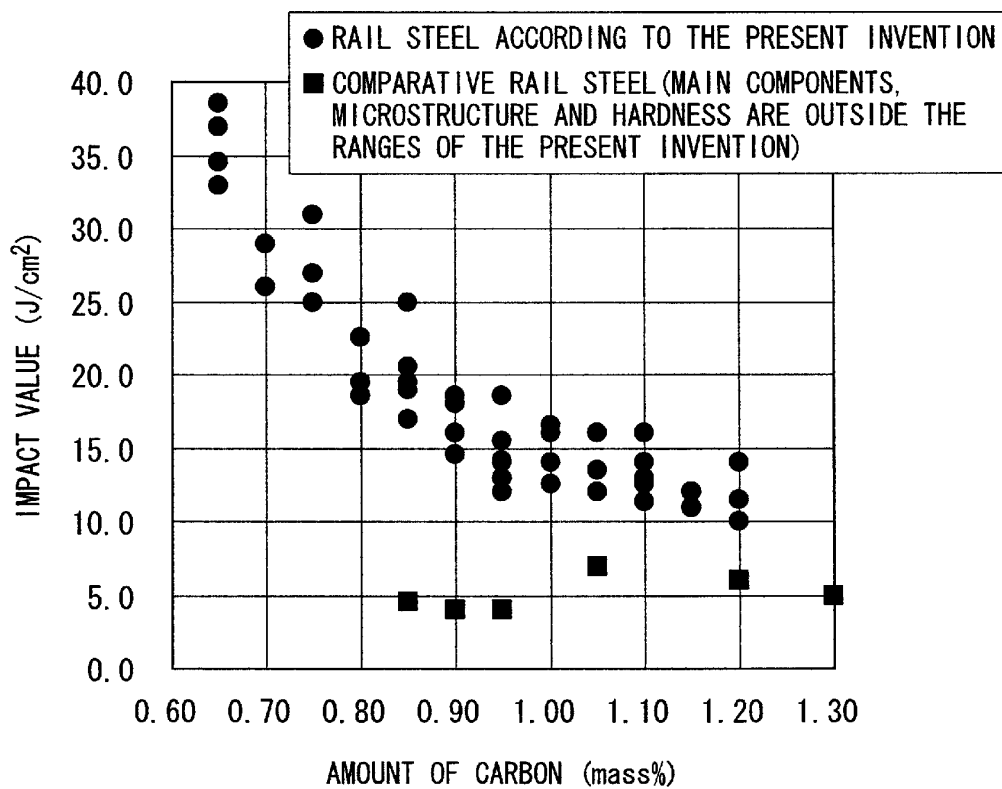


FIG. 10

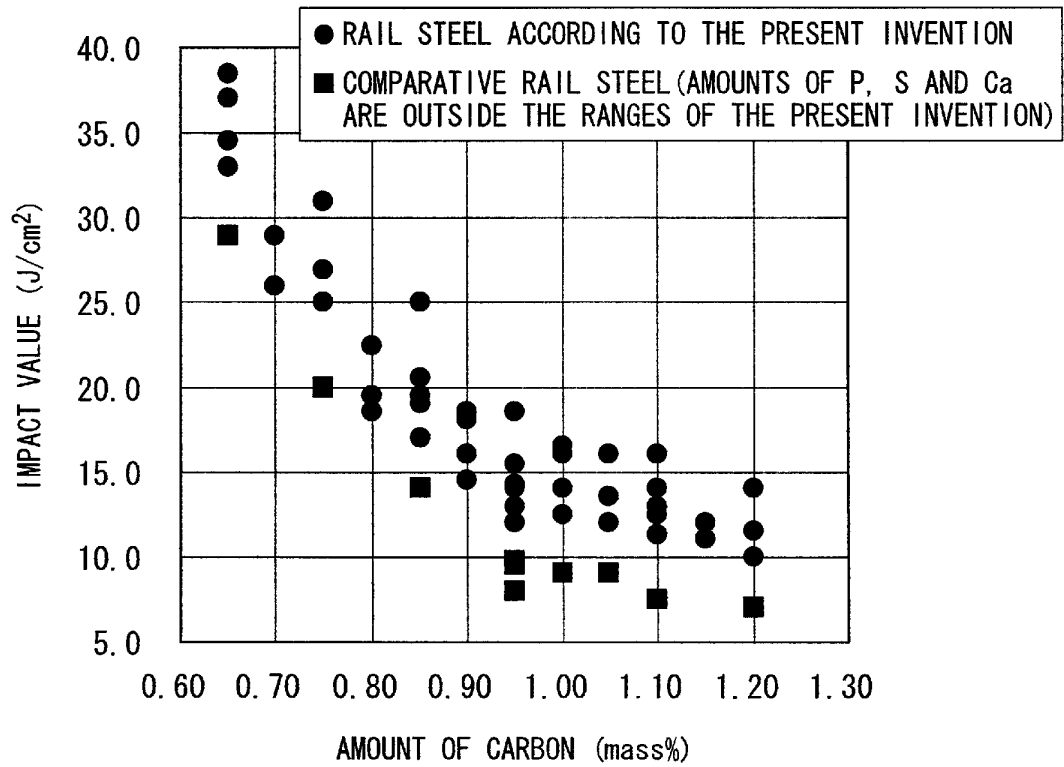
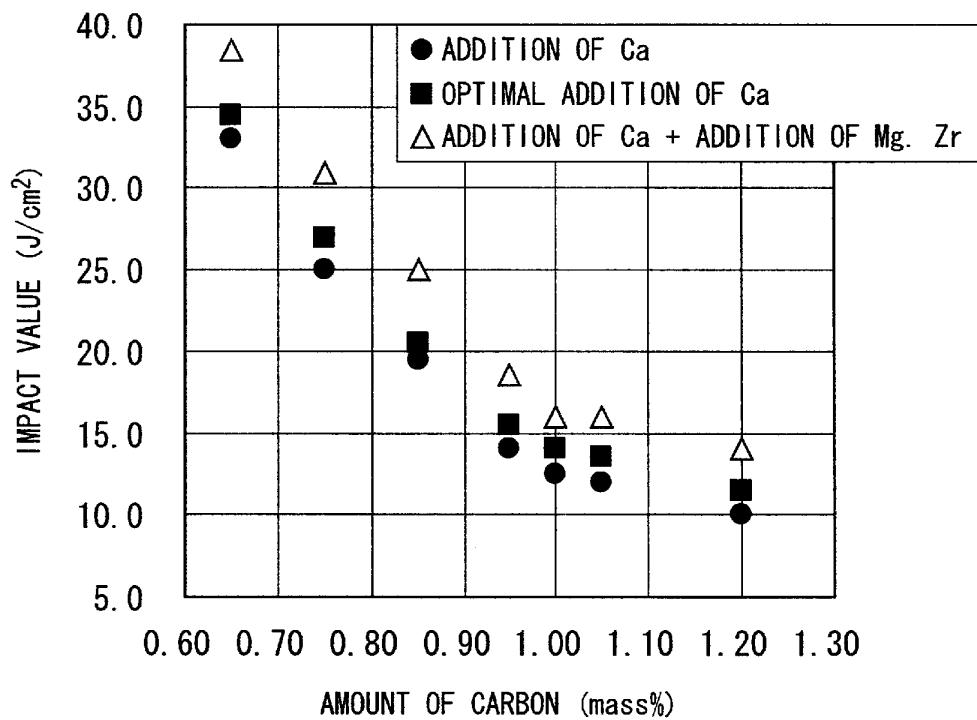


FIG. 11



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2009/005800

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/04 (2006.01) i, C22C38/58 (2006.01) i, C21C7/00 (2006.01) n, C21C7/04 (2006.01) n

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C38/00-38/60, C21C7/00-7/04

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2010
Kokai Jitsuyo Shinan Koho	1971-2010	Toroku Jitsuyo Shinan Koho	1994-2010

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2008-050684 A (JFE Steel Corp.), 06 March 2008 (06.03.2008), claims; paragraphs [0018] to [0020]; tables 1, 3 (Family: none)	1-11
A	JP 2007-169727 A (JFE Steel Corp.), 05 July 2007 (05.07.2007), claims; paragraphs [0018], [0019], [0026]; tables 1, 3 (Family: none)	1-11
A	JP 2002-363702 A (Nippon Steel Corp.), 18 December 2002 (18.12.2002), claims (Family: none)	1-11

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

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Date of the actual completion of the international search
18 January, 2010 (18.01.10)Date of mailing of the international search report
02 February, 2010 (02.02.10)Name and mailing address of the ISA/
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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2009/005800

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2006-111939 A (Nippon Steel Corp.), 27 April 2006 (27.04.2006), claims; paragraphs [0021], [0022] (Family: none)	1-11
A	JP 2001-020040 A (Nippon Steel Corp.), 23 January 2001 (23.01.2001), claims; paragraphs [0030], [0031] (Family: none)	1-11
A	JP 2005-256023 A (Nippon Steel Corp.), 22 September 2005 (22.09.2005), claims; paragraphs [0041], [0042] (Family: none)	1-11

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REFERENCES CITED IN THE DESCRIPTION

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- JP 2007291413 A [0018]
- JP H08246100 B [0071]
- JP H09111352 B [0071]