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# (54) HOT-ROLLED BAR MEMBER, PART, AND HOT-ROLLED BAR MEMBER MANUFACTURING METHOD

(57) The present invention adopts a hot rolled bar or hot rolled wire rod including a chemical composition including, by mass%, C: 0.05 to 0.30%, Si: 0.30 to 0.60%, Mn: 0.40 to 1.0%, S: 0.008 to less than 0.040%, Cr: 1.60 to 2.00%, Mo: 0.1% or less, Al: 0.025 to 0.05%, N: 0.010 to 0.025%, Ti: 0.003% or less, Bi: 0.0001 to 0.0050%, and a remainder including Fe and impurities, in which amounts of P and O in the impurities are respectively P: 0.025% or less and O: 0.002% or less; in which a microstructure includes ferrite-pearlite or ferrite-pearlite-bainite, and an Expression (1) is satisfied.

$$1.70 \leq Cr + 2 \times Mo \leq 2.10 \quad \ldots (1)$$

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## Description

[Technical Field of the Invention]

**[0001]** The present invention relates to a hot rolled bar or hot rolled wire rod, a component, and a manufacturing method of a hot rolled bar or hot rolled wire rod.

**[0002]** Priority is claimed on Japanese Patent Application No. 2015-071714, filed on March 31, 2015, the content of which is incorporated herein by reference.

[Related Art]

**[0003]** Mechanical components such as gears or pulleys are used in vehicles or industrial machines. A lot of these mechanical components are manufactured by the following method. A material made of alloy steel for machine structural use is prepared. The material is, for example, a hot rolled bar or hot rolled wire rod having a chemical composition corresponding to SCr420, SCM420, or SNCM420 based on JIS. First, the material is subjected to normalizing, if necessary. Next, the material is subjected to machining. A surface hardening treatment is performed on the cut intermediate product. The surface hardening treatment is, for example, carburizing hardening, carbonitriding hardening, or induction hardening. Tempering is performed on the intermediate product subjected to surface hardening at a tempering temperature of 200°C or lower. A shot peening treatment is performed on the tempered intermediate product, if necessary. With the processes described above, a mechanical component is manufactured.

**[0004]** In recent years, the weight of a mechanical component has reduced or the size thereof has decreased, in order to improve the fuel efficiency of vehicles or to deal with high output of an engine. Loads applied on mechanical components are increased compared to those of the related art. Accordingly, excellent bending fatigue strength, surface fatigue strength (contact fatigue strength), and wear resistance are necessary for mechanical components.

**[0005]** Patent Document 1 discloses steel for a gear including Si: 0.1% or less, and P: 0.01% or less. The steel for a gear disclosed in Patent Document 1 has high strength and high reliability with toughness, by decreasing the Si content and P content.

**[0006]** Patent Document 2 discloses steel for a gear including Cr: 1.50 to 5.0%, and Si: 0.40 to 1.0%, in which a relationship of
$7.5\% > 2.2 \times Si(\%) + 2.5 \times Mn(\%) + Cr(\%) + 5.7 \times Mo(\%)$ is satisfied, if necessary. The steel for a gear disclosed in Patent Document 2 has excellent tooth surface strength by including such chemical composition.

**[0007]** Patent Document 3 discloses steel for a carburized gear including Si: 0.35 to 3.0% or less, V: 0.05 to 0.5%, and the like. The steel for a carburized gear disclosed in Patent Document 3 has high bending fatigue strength and high surface fatigue strength by including such chemical composition.

**[0008]** Patent Document 4 discloses case hardening steel which improves machinability by controlling a solidification rate during casting and finely dispersing sulfides, in order to prevent coarse sulfides.

**[0009]** Patent Document 5 discloses a steel bar for hot forging and a wire rod including Si: 0.30 to 0.60%, and Cr: 1.60 to 2.00%, in which Cr content and Mo content are regulated. The steel bar for hot forging and the wire rod disclosed in Patent Document 5 satisfy both fatigue strength and machinability.

**[0010]** Patent Document 6 discloses case hardening steel having excellent low cycle fatigue strength accompanied with a large strain, by strictly controlling alloy elements to improve plastic deformation resistance and grain boundary strength.

[Prior Art Document]

[Patent Document]

**[0011]**

[Patent Document 1] Japanese Unexamined Patent Application, First Publication No. S60-21359

[Patent Document 2] Japanese Unexamined Patent Application, First Publication No. H7-242994

[Patent Document 3] Japanese Unexamined Patent Application, First Publication No. H7-126803

[Patent Document 4] Japanese Patent No. 5114689

[Patent Document 5] Japanese Patent No. 5561436

[Patent Document 6] Japanese Unexamined Patent Application, First Publication No. H10-259450

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

**[0012]** However, since the surface fatigue strength of the steel for a gear disclosed in Patent Document 1 has not been investigated, the surface fatigue strength thereof may be low. In addition, since the bending fatigue strength of the steel for a gear disclosed in Patent Document 2 has not been investigated, the bending fatigue strength thereof may be low. The steel for carburized gear disclosed in Patent Document 3 includes V. However, V increases hardness of steel after hot rolling or hot forging. Accordingly, machinability of steel after hot rolling or hot forging may be deteriorated.

**[0013]** In addition, the surface fatigue strength and bending fatigue strength of the case hardening steel disclosed in Patent Document 4 has not been investigated, and these may be low. The steel bar for hot forging disclosed in Patent Document 5 satisfies high bending fatigue strength, surface fatigue strength, and machinability, by regulating the total amount of Cr and Mo contents. However, since segregation in the steel bar for hot forging disclosed in Patent Document 5 has not been considered, machinability may be insufficient, in a case of mass production. Regarding the case hardening steel disclosed in Patent Document 6, only the improvement of low cycle fatigue strength is shown, and bending fatigue strength, surface fatigue strength, wear resistance, and machinability thereof have not been investigated.

**[0014]** As described above, Patent Document 1 to Patent Document 6 do not disclose steel having excellent bending fatigue strength, surface fatigue strength, and wear resistance and excellent machinability.

**[0015]** The present invention has been made to address the aforementioned problems and an object of the present invention is to provide a hot rolled bar or hot rolled wire rod having excellent bending fatigue strength, surface fatigue strength, wear resistance, and machinability, a component, and a manufacturing method thereof.

[Means for Solving the Problem]

**[0016]** In the related art, it is known that steel having excellent bending surface fatigue strength after carburizing or carbonitriding is obtained, by adjusting Si, Cr, and Mo contents. However, since bending surface fatigue strength and machinability are conflicting with each other in general, it is not possible to satisfy both bending surface fatigue strength and machinability at a high level. Therefore, the inventors completed investigations and research for the development of a hot rolled bar or hot rolled wire rod in which bending surface fatigue strength and machinability can be satisfied at a high level, and as a result, the following findings were obtained.

(a) When Si content is large, surface fatigue strength and wear resistance of steel are increased. In addition, when Cr content and Mo content are large, bending fatigue strength, surface fatigue strength, and wear resistance of steel are increased.

(b) When the Mo content is increased, generation of a bainite structure is promoted, in addition to a ferrite structure and a pearlite structure, after hot rolling or hot forging, or after further normalizing. Accordingly, steel is hardened, and thus, machinability is deteriorated. In addition, even in a case where Mo is not added, when the Cr content is excessively large, the generation of a bainite structure is promoted, in the same manner as described above. Accordingly, machinability is deteriorated.

(c) As described above, it was found that, in order to obtain excellent bending fatigue strength, surface fatigue strength, wear resistance, and machinability of the hot rolled bar or hot rolled wire rod, it is preferable that the total amount of the Cr and the Mo contents is adjusted, in addition to the regulation of each Si, Cr, and Mo content. Specifically, it is determined that, when chemical composition of the steel satisfies Expression (1), excellent bending fatigue strength, surface fatigue strength, wear resistance, and machinability are obtained. Each element symbol in Expression (1) represents the amount of the corresponding element (mass%).

$$1.70 \leq Cr + 2 \times Mo \leq 2.10 \quad \ldots(1)$$

(d) As described above, in order to increase machinability of the hot rolled bar or hot rolled wire rod, it is necessary to prevent generation of a bainite structure after hot forging or after further normalizing. In order to prevent generation of a bainite, it is preferable to adjust Cr and Mo contents which are elements for increasing hardenability.

(e) Meanwhile, in a case where microsegregation of Mn in the hot rolled bar or hot rolled wire rod is large, the machinability tended to be deteriorated. Even when the Cr and Mo contents are adjusted, an amount of bainite generation may be increased due to the microsegregation of Mn and the machinability may be insufficient, in a case of mass production.

(f) Mn is microsegregated in steel during continuous casting, and this microsegregation is not removed during rolling and forging and remains in the steel. Since Mn is microsegregated, generation of a bainite structure is promoted, in addition to a ferrite structure and a pearlite structure in the steel, even after hot rolling or hot forging, or after further normalizing. Accordingly, the steel is hardened, and thus, machinability is deteriorated.

(g) By decreasing microsegregation of Mn in a slab obtained by casting from molten steel, generation of a hard bainite structure due to the microsegregation is prevented and machinability is improved in the hot rolled bar or hot rolled wire rod. More specifically, when the slab satisfies Expression (2), machinability of the hot rolled bar or hot rolled wire rod is increased. In addition, Mn in Expression (2) represents the Mn content (mass%) in the steel and $Mn_{max}$ represents the Mn content in the space between primary arms of a dendrite in the slab.

$$Mn_{max}/Mn<2.4 \quad ...(2)$$

**[0017]** $Mn_{max}$ is obtained by the following method. A test piece having a width of 50 mm × a length of 50 mm × a thickness of 8 mm in a thickness direction is collected from a surface layer of a manufactured continuous cast slab. A surface having a width of 50 mm × a length of 50 mm is set as a "test surface". After performing resin embedding of the test piece, the test surface is mirror polished.

**[0018]** In the measurement for distribution of the Mn contents, Electron Probe Micro Analyzer (EPMA) is used. A beam diameter at the time of the measurement using the EPMA is set as 1 μm, and linear analysis is performed within a range of 50 mm in parallel with a surface at a position separated by 15 mm from a slab surface.

**[0019]** The distribution of the Mn contents in space between the primary arms of the dendrite is measured by the linear analysis using the EPMA, and a maximum value of the measured Mn contents is set as the Mn content in the space between dendrites. A value of Expression (2) is defined as a value obtained by dividing the Mn content in the space between dendrites measured by the linear analysis by an average Mn content in the slab measured in advance.

**[0020]** In a case where the value of Expression (2) is 1.0, this case indicates an ideal state in which there is no difference between Mn contents in a core and the space between the primary arm of the dendrite in the slab and no segregation of Mn is generated. When a percentage of the Mn segregation is high, a difference between Mn contents in the core and in the space between primary arms of the dendrite in the slab is large, a lot of hard bainite structures are generated, and machinability is deteriorated.

**[0021]** The hot rolled bar or hot rolled wire rod of the present invention was completed based on the aforementioned findings. Hereinafter, the hot rolled bar or hot rolled wire rod according to the present invention will be described in detail. Hereinafter, "%" of the amounts of elements configuring a chemical composition means "mass%".

(1) According to the present invention, there is provided a hot rolled bar or hot rolled wire rod including a chemical composition including, by mass%,

C: 0.05 to 0.30%,
Si: 0.30 to 0.60%,
Mn: 0.40 to 1.0%,
S: 0.008 to less than 0.040%,
Cr: 1.60 to 2.00%,
Mo: 0 to 0.1%,
Al: 0.025 to 0.05%,
N: 0.010 to 0.025%,
Ti: 0 to 0.003%,
Bi: 0.0001 to 0.0050%, and

a remainder including Fe and impurities,
in which amounts of P and O in the impurities are respectively

P: 0.025% or less and
O: 0.002% or less;

in which a microstructure includes ferrite-pearlite or ferrite-pearlite-bainite, and an Expression (1) is satisfied.

$$1.70 \leq Cr + 2 \times Mo \leq 2.10 \ldots (1)$$

**[0022]** Here, an element symbol in the Expression (1) represents an amount of a corresponding element (mass%).

(2) According to the present invention, the hot rolled bar or hot rolled wire rod according to (1) may include, instead of a part of Fe, by mass%, Nb: 0.08% or less.
(3) According to the present invention, the hot rolled bar or hot rolled wire rod according to (1) or (2) may include, instead of a part of Fe, one or more elements selected from Cu: 0.40% or less and Ni: 0.80% or less.
(4) According to the present invention, there is provided a component obtained by machining the hot rolled bar or hot rolled wire rod according to any one of (1) to (3).
(5) According to the present invention, there is provided a manufacturing method of a hot rolled bar or hot rolled wire rod, including: manufacturing a slab including a chemical composition according to any one of (1) to (3) by continuous casting or ingot casting, in which a ratio of Mn contents ($Mn_{max}$/Mn) satisfies an Expression (2); and hot rolling the slab.

$$Mn_{max}/Mn < 2.4 \ldots (2)$$

**[0023]** Here, in the Expression (2), the $Mn_{max}$ represents a Mn content in a space between primary arms of a dendrite and the Mn represents a Mn content in a steel (mass%).

[Effects of the Invention]

**[0024]** The hot rolled bar or hot rolled wire rod of the present invention has excellent bending fatigue strength, surface fatigue strength, wear resistance, and machinability.

[Brief Description of the Drawings]

**[0025]**

FIG. 1 is a side view of a small roller test piece for a roller pitching test, manufactured in Examples.
FIG. 2 is a side view of an Ono-type rotating bending fatigue test piece with notches manufactured in Examples.
FIG. 3 is a view showing carburizing hardening conditions of Examples.
FIG. 4 is a front view of a large roller for a roller pitching test of Examples.

[Embodiments of the Invention]

**[0026]** Hereinafter, a hot rolled bar or hot rolled wire rod of the present invention will be described in detail.
**[0027]** The amounts of elements of the hot rolled bar or hot rolled wire rod will be described. Here, "%" regarding the elements indicates mass%.

(C: 0.05 to 0.30%)

**[0028]** Carbon (C) increases tensile strength and fatigue strength of steel. Meanwhile, when a C content is excessively large, machinability of the steel is deteriorated. Therefore, the C content is 0.05 to 0.30%. The preferable C content is 0.10 to 0.28% and the C content is more preferably 0.15 to 0.25%.

(Si: 0.30 to 0.60%)

**[0029]** Silicon (Si) increases hardenability of steel. Si further increases resistance to temper softening of the steel. Accordingly, Si increases surface fatigue strength and wear resistance of steel. Meanwhile, when Si is excessively included, strength of steel after hot rolling or hot forging is excessively increased. As a result, machinability of steel is deteriorated. When Si is excessively included, bending fatigue strength is also decreased. Therefore, Si content is 0.30 to 0.60%. A preferable lower limit of the Si content is larger than 0.30%, and the lower limit thereof is more preferably 0.40% or more and even more preferably 0.45% or more. A preferable upper limit of the Si content is less than 0.60%, and the upper limit thereof is more preferably 0.57% or less and even more preferably 0.55% or less.

(Mn: 0.40 to 1.0%)

**[0030]** Manganese (Mn) increases hardenability of steel and increases strength of steel. Accordingly, Mn increases strength of a core in a mechanical component subjected to carburizing hardening or carbonitriding hardening. Meanwhile, when Mn is excessively included, machinability of steel after hot rolling or hot forging is deteriorated. In addition, Mn is easily segregated in the space between dendrites. Due to the segregation, a hard bainite is easily generated and machinability is deteriorated. Therefore, Mn content is 0.40 to 1.0%. A preferable lower limit of the Mn content exceeds 0.50%, and the lower limit thereof is more preferably 0.55% or more and even more preferably 0.60% or more. A preferable upper limit of the Mn content is less than 1.0%, and the upper limit thereof is more preferably 0.95% or less and even more preferably 0.9% or less.

(S: 0.008 to less than 0.040%)

**[0031]** Sulfur (S) is combined with Mn to form MnS. MnS increases machinability of steel. Meanwhile, when S is excessively included, coarse MnS is formed. The coarse MnS decreases bending fatigue strength and surface fatigue strength of steel. Therefore, S content is 0.008 to less than 0.040%. A preferable lower limit of the S content exceeds 0.008%, and the lower limit thereof is more preferably 0.009% or more and even more preferably 0.010% or more. A preferable upper limit of the S content is 0.030% or less, and the upper limit thereof is more preferably less than 0.030% and even more preferably less than 0.020%.

(Cr: 1.60 to 2.00%)

**[0032]** Chrome (Cr) increases hardenability of steel and resistance to temper softening of steel. Accordingly, Cr increases bending fatigue strength, surface fatigue strength, and wear resistance of steel. Meanwhile, when Cr is excessively included, generation of a bainite is promoted in steel after hot rolling, after hot forging, or after normalizing. Accordingly, machinability of steel is deteriorated. Therefore, Cr content is 1.60 to 2.00%. A preferable lower limit of the Cr content exceeds 1.60%, and the lower limit thereof is more preferably 1.70% or more and even more preferably 1.80% or more. A preferable upper limit of the Cr content is less than 2.00%, and the upper limit thereof is more preferably 1.95% or less and even more preferably 1.90% or less.

(Mo: 0 to 0.10% (0.10% or less and including 0%))

**[0033]** Molybdenum (Mo) may be included or may not be included. Mo increases hardenability of steel and resistance to temper softening. Accordingly, Mo increases bending fatigue strength, surface fatigue strength, and wear resistance of steel. Meanwhile, when Mo is excessively included, generation of a bainite is promoted in steel after hot rolling, after hot forging, or after normalizing. Accordingly, machinability of steel is deteriorated. Therefore, Mo content is 0 to 0.10%. A preferable lower limit of the Mo content is 0.02% or more. A preferable upper limit of the Mo content is less than 0.10%, and the upper limit thereof is more preferably 0.08% or less and even more preferably 0.05% or less.

(Al: 0.025 to 0.05%)

**[0034]** Aluminum (Al) deoxidizes steel. Al is also combined with N to form AlN. The AlN prevents coarsening of austenite grains due to carburizing and heating. Meanwhile, when Al is excessively included, coarse Al oxides are formed. The coarse Al oxides decrease bending fatigue strength of steel. Therefore, Al content is 0.025 to 0.05%. A preferable lower limit of the Al content exceeds 0.025%, and the lower limit thereof is more preferably 0.027% or more and even more preferably 0.030% or more. A preferable upper limit of the Al content is less than 0.05%, and the upper limit thereof is more preferably 0.045% or less and even more preferably 0.04% or less.

(N: 0.010 to 0.025%)

**[0035]** Nitrogen (N) is combined with Al or Nb to form AlN or NbN. The AlN or the NbN prevents coarsening of austenite grains due to heating for carburizing. Meanwhile, when N is excessively included, it is difficult to stably manufacture steel in steel making process. Therefore, N content is 0.010 to 0.025%. A preferable lower limit of the N content exceeds 0.010%, and the lower limit thereof is more preferably 0.012% or more and even more preferably 0.013% or more. A preferable upper limit of the N content is less than 0.025%, and the upper limit thereof is more preferably 0.020% or less and even more preferably 0.018% or less.

(Ti: 0 to 0.003% (0.003% or less and including 0%))

**[0036]** Titanium (Ti) is combined with N to form coarse TiN. The coarse TiN decreases fatigue strength of steel. Therefore, it is preferable that Ti content is as small as possible. The Ti content is 0 to 0.003%. A preferable upper limit of the Ti content is less than 0.003% and the upper limit thereof is more preferably 0.002% or less.

(Bi: 0.0001% to less than 0.0050%)

**[0037]** Bi is an important element in the present invention. A small amount of Bi becomes an inoculant nucleus of solidification, decreases a dendrite arm spacing during solidification, and refines a solidifated structure. As a result, the segregation amount of an element which is easily segregated, such as Mn, is decreased, generation of a bainite structure due to microsegregation is prevented, and machinability is improved. In order to obtain a refining effect of the solidificated structure, it is necessary that the Bi content is set to be 0.0001% or more. However, when the Bi content is set to be 0.0050% or more, the refining effect of the solidificated structure is saturated, hot workability of steel is deteriorated, and it is difficult to hot roll. From these viewpoints, in the present invention, the Bi content is 0.0001 % or more and less than 0.0050%. In order to further improve machinability, the Bi content is preferably 0.0010% or more.

(P: 0.025% or less)

**[0038]** Phosphor (P) is an impurity. P decreases fatigue strength or hot workability of steel. Therefore, P content is preferably small. The P content is 0.025% or less. The preferable P content is less than 0.025% and the P content is more preferably 0.020% or less.

(O (oxygen): 0.002% or less)

**[0039]** Oxygen (O) is combined with Al to form an oxide inclusion. The oxide inclusion decreases bending fatigue strength of steel. Therefore, it is preferable that an O content is as small as possible. The O content is 0.002% or less. The preferable O content is less than 0.002% and the O content is more preferably 0.001% or less. It is more desirable that the O content is as small as possible, within a range not causing an increase in cost in steel making process.

**[0040]** The chemical composition of the hot rolled bar or hot rolled wire rod according to the embodiment may include Nb, instead of a part of Fe.

(Nb: 0 to 0.08% (0.08% or less and including 0%))

**[0041]** Niobium (Nb) is a selective element. Nb is combined with C and N to form Nb carbide, Nb nitride, or Nb carbonitride. The Nb carbide, Nb nitride, and the Nb carbonitride prevent coarsening of austenite grains during carburizing and heating, in the same manner as the Al nitride. If a small amount of Nb is included, the effect described above is obtained. Meanwhile, when Nb is excessively included, the Nb carbide, the Nb nitride, and the Nb carbonitride are coarsened. Accordingly, the coarsening of austenite grains during carburizing and heating cannot be prevented. Therefore, Nb content is 0.08% or less. A preferable lower limit of the Nb content is 0.01 % or more. A preferable upper limit of the Nb content is less than 0.08%, and the upper limit thereof is more preferably 0.05% or less.

**[0042]** The remainder of the chemical composition of the hot rolled bar or hot rolled wire rod according to the embodiment is Fe and impurities. The impurities in the embodiment are elements mixed from ores or scraps used as a raw material for steel, or are elements mixed in an environment of manufacturing process. In the embodiment, the impurities are, for example, copper (Cu) or nickel (Ni). The Cu and Ni contents which are the impurities are approximately the same as the Cu and Ni contents in SCr steel and SCM steel regulated as JIS G4053 alloy steel for machine structural use, the Cu content is 0.40% or less and the Ni content is 0.80% or less.

(Ni: 0 to 0.8% (0.8% or less and including 0%))

**[0043]** Nickel (Ni) has an effect of increasing hardenability and is an element effective for further increasing fatigue strength. Thus, nickel may be included, if necessary. However, when the Ni content is excessively included, not only the effect for increasing fatigue strength along with the improvement of hardenability is saturated, but also a bainite structure is easily generated in steel after hot rolling, after hot forging, or after a normalizing treatment. Therefore, the amount of Ni in a case of including Ni is set as 0.80% or less. The amount of Ni in a case of including Ni is preferably 0.60% or less. In addition, in order to stably obtain the effect for increasing fatigue strength along with the improvement of hardenability, the amount of Ni in a case of including Ni is preferably 0.10% or more.

(Cu: 0 to 0.40% (0.40% or less and including 0%))

**[0044]** Copper (Cu) has an effect for increasing hardenability and is an element effective for further increasing fatigue strength. Thus, copper may be included, if necessary. However, when the Cu content is excessively included, deterioration in hot ductility and hot workability becomes significant. Therefore, the amount of Cu in a case of including Cu is set as 0.40% or less. In addition, the amount of Cu in a case of including Cu is preferably 0.30 or less. A preferable lower limit of the Cu content is 0.1% or more.

[Expression (1)]

**[0045]** In addition, in the chemical composition of the hot rolled bar or hot rolled wire rod according to the embodiment, F1 defined in Expression (1) is 1.70 to 2.10.

$$F1=Cr+2\times Mo \ldots(1)$$

**[0046]** Here, a symbol for an element in Expression F1 represents the amount of the corresponding element (mass%).

**[0047]** As described above, both Cr and Mo increase hardenability of steel and resistance to temper softening, and increase surface fatigue strength and wear resistance. In addition, Cr and Mo increase bending fatigue strength of steel. When Mo and Cr are compared with each other, Mo exhibits approximately the same effect (improvement for bending fatigue strength, surface fatigue strength, and wear resistance) as that of Cr with the content which is half of the Cr content. Therefore, an expression of $F1=Cr+2\times Mo$ is defined. Each symbol for an element in F1 represents the amount of the corresponding element (Cr and Mo) (mass%).

**[0048]** When F1 is less than 1.70, at least one of bending fatigue strength, surface fatigue strength, and wear resistance of steel is decreased. On the other hand, when F1 exceeds 2.10, the generation of a bainite is promoted in steel after hot rolling, after hot forging, or after normalizing. Therefore, machinability of steel is deteriorated. When F1 is 1.70 to 2.10, it is possible to increase bending fatigue strength, surface fatigue strength, and wear resistance of steel, while preventing deterioration in machinability of steel. A preferable lower limit of F1 is 1.80 or more. A preferable upper limit of F1 is less than 2.00.

[Expression (2)]

**[0049]** When Mn is microsegregated in steel slab used when manufacturing the hot rolled bar or hot rolled wire rod of the present invention by hot rolling, the generation of a hard bainite structure is promoted in the microstructure of steel after hot rolling and machinability is deteriorated. Therefore, it is preferable that microsegregation of Mn is prevented in the steel slab. Even when Expression (1) is satisfied, when microsegregation of Mn is large, the amount of the hard bainite structure is increased and machinability is deteriorated.

**[0050]** Therefore, when Expression (2) is satisfied, microsegregation of Mn is small, the generation of the hard bainite structure is prevented, and machinability is improved.

$$Mn_{max}/Mn<2.4 \ldots(2)$$

**[0051]** A left side of Expression (2) is defined as $F2=Mn_{max}/Mn$. In a case where a value of F2 does not satisfy Expression (2), when the microsegregation of Mn is large, the amount of the hard bainite structure is increased in steel, and machinability is deteriorated. In other words, even when the value of F1 satisfies Expression (1), when the value of F2 does not satisfy Expression (2), the generation of the hard bainite structure due to the microsegregation of Mn is promoted and machinability does not satisfy a target value.

[Microstructure]

**[0052]** In a case where the microstructure (phase) of the hot rolled bar or hot rolled wire rod includes a martensite, cracks easily occurs during straightening or transporting of a hot rolled steel bar or a wire rod, since martensite is hard and ductility is low. Therefore, the hot rolled bar or hot rolled wire rod of the present invention includes a ferrite-pearlite structure or a ferrite-pearlite-bainite structure.

[Manufacturing Method]

**[0053]** A manufacturing method of a hot rolled bar or hot rolled wire rod according to an embodiment of the present invention will be described.

[Continuous casting process]

**[0054]** A slab which satisfies the chemical composition described above and in which a ratio of the Mn contents ($Mn_{max}$/Mn) satisfies Expression (2) is manufactured. Here, in the Expression (2), $Mn_{max}$ represents Mn content in space between primary arms of a dendrite and Mn represents Mn content in steel. A slab may be obtained by continuous casting steel including the chemical composition or a steel ingot may be obtained by ingot casting steel including the chemical composition. In the casting conditions, for example, a mold having a size of 220 mm × 220 mm is used, a superheat temperature of molten steel in a tundish is set as 10°C to 50°C, and a casting speed is set as 1.0 m/min to 1.5 m/min.

**[0055]** In addition, in order to prevent Mn segregation generated in the casting process, it is desired that an average cooling rate in a temperature range from a liquidus temperature to a solidus temperature at a position of depth of 15 mm from a slab surface is set to 100 °C/min or faster and 500 °C/min or lower, when casting the molten steel including the chemical composition described above. Regarding the average cooling rate in a temperature range from a liquidus temperature to a solidus temperature at a position of depth of 15 mm from the slab surface, a cross section of the obtained slab can be etched with picric acid, a space $\lambda$ ($\mu$m) between primary arms of a dendrite at a position of depth of 15 mm from the slab surface can be measured, and an average cooling rate A (°C/min) within a temperature range from a liquidus temperature to a solidus temperature can be calculated using the space between primary arms of a dendrite based on the following expression.

$$\lambda=710\times A^{-0.39}$$

**[0056]** When the average cooling rate in the temperature range described above is lower than 100 °C/min, solidification is excessively slow. Accordingly, the space between dendrites is widened, segregation of Mn is generated, a bainite structure due to microsegregation is excessively generated, and machinability is deteriorated. On the other hand, when the average cooling rate is 500 °C/min or faster, a solidification structure becomes uneven and cracks due to the uneven structure may occur.

**[0057]** The temperature range from a liquidus temperature to a solidus temperature is a temperature range from the start of solidification to the end of solidification. Accordingly, the average cooling temperature in this temperature range means the average solidification rate of the slab. The average cooling rate described above, can be achieved, for example, by a method of controlling a size of a cross section of a mold or a casting speed to a proper value or increasing the amount of cooling water used for water cooling, immediately after casting. Both of continuous casting and ingot casting can be applied.

**[0058]** Next, the manufactured slab is inserted into a heating furnace, heated at a heating temperature of 1250°C to 1300°C for 10 hours or longer, and subjected to blooming, to manufacture a billet. The heating temperature described above means an average temperature in the furnace and the heating time means an in-fumace time.

**[0059]** The billet obtained as described above is inserted into a heating furnace, heated at a heating temperature of 1250°C to 1300°C for 1.5 hours or longer, and hot rolled by setting the finish temperature as 900°C to 1100°C. After finish rolling, cooling in the atmosphere is performed under the conditions in which cooling rate becomes equal to or lower than a cooling rate in naturally cooling.

**[0060]** After finish rolling, cooling may be performed to reach room temperature, under the conditions in which the cooling rate becomes equal to or lower than a cooling rate in naturally cooling, but, in order to increase productivity, it is preferable to perform the cooling by suitable methods such as air cooling, mist cooling, and water cooling at a point when the temperature has reached 600°C.

**[0061]** The heating temperature means an average temperature in the furnace and the heating time means the in-furnace time. In addition, the finish temperature of the hot rolling means a surface temperature of a bar or hot rolled wire rod at an exit of final stand in a roller including a plurality of stands. The cooling rate after finish rolling indicates a cooling rate at the surface of the bar or hot rolled wire rod.

**[0062]** When processing the billet to the hot rolled bar or hot rolled wire rod by hot rolling, a reduction of area (RD) represented by Expression (3) is preferably 87.5% or greater.

$$RD = \{1 - (\text{cross section area of steel bar or hot rolled wire rod/cross section area of billet})\} \times 100 \ldots(3)$$

**[0063]** The cross section area means an area of a cross section perpendicular to a longitudinal direction, that is, an area of a transverse section.
**[0064]** In this manner, the hot rolled bar or hot rolled wire rod of the embodiment is manufactured.
**[0065]** In addition, a component made of the hot rolled bar or hot rolled wire rod is manufactured, if necessary, by normalizing the hot rolled bar or hot rolled wire rod, further performing a surface effect treatment, and cutting an intermediate product after the surface hardening treatment into a predetermined shape by cutting.

[Examples]

**[0066]** Steels 1 to 35 including a chemical composition shown in Table 1 were melted in a 270 ton converter furnace and subjected to continuous casting using a continuous casting machine, to manufacture a slab having a size of 220 mm × 220 mm. In addition, the reduction was added during solidification in continuous casting. In the casting conditions, a mold having a size of 220 mm × 220 mm was used, a superheat temperature of molten steel in a tundish was set as 10°C to 50°C, and a casting speed was set as 1.0 m/min to 1.5 m/min. In addition, in the continuous casting, a change of an average cooling rate in a temperature range from a liquidus temperature to a solidus temperature at a position of a depth of 15 mm from a surface of the slab was performed by changing the amount of cooling water of the mold.
**[0067]** The steels 1 to 15 in Table 1 are steels including the chemical composition regulated in the present invention. The steels 16 to 35 are steels of Comparative Examples in which the chemical composition are out of the conditions regulated in the present invention, steels of Comparative Examples in which the average cooling rate is out of the desired range, or steels of Comparative Examples in which the value of F1 or the value of F2 is out of the desired range. Underlined numerical values in Table 1 indicate that the values are out of the range of the hot rolled bar or hot rolled wire rod for hot forging according to the embodiment.
**[0068]** Using the slab obtained by continuous casting as a material, blooming and hot rolling were performed to manufacture a trial steel bar (hot rolled bar or hot rolled wire rod). In the examples, in order to collect a test piece for $Mn_{max}$ measurement, the slab was temporarily cooled to room temperature.
**[0069]** Then, the slab of each mark was heated at 1250°C for 2 hours. The heated slab was hot rolled to manufacture a plurality of round bars having a diameter of 35 mm. After the hot rolling, the round bars were naturally cooled in the atmosphere. In this manner, various hot rolled bars or hot rolled wire rods were manufactured.
**[0070]** The blooming was performed after inserting the manufactured slab into a heating furnace and heating the slab at a heating temperature of 1250°C to 1300°C for 10 hours or longer. In addition, the hot rolling was performed by setting a finish temperature as 900°C to 1100°C, after inserting the slab subjected to the blooming into a heating furnace and heating the slab at a heating temperature of 1250°C to 1300°C for 1.5 hours or longer. After finish rolling, cooling in the atmosphere was performed under the conditions in which cooling rate becomes equal to or lower than a cooling rate in naturally cooling. A reduction of area (RD) from the slab to the hot rolling was 87.5% or greater.
**[0071]** Whether or not surface cracks occur during casting was visually determined and results thereof are shown in Table 1.

[Measurement Method of $Mn_{max}$]

**[0072]** The $Mn_{max}$ was acquired by the following method. A test piece having a width of 50 mm × a length of 50 mm × a thickness of 8 mm in a thickness direction was collected from a surface layer of the manufactured slab, and a surface having a width of 50 mm × a length of 50 mm was set as a "test surface". After performing resin embedding of the test piece, the test surface was mirror polished. In the measurement for distribution of the Mn contents, EPMA was used. A beam diameter at the time of the measurement using EPMA was set as 1 μm, and linear analysis was performed within a range of 50 mm in parallel with a surface at a position separated by 15 mm from a slab surface. The distribution of the Mn contents between the primary arms of the dendrite was measured by linear analysis using EPMA, and a maximum value of the measured Mn contents was set as the Mn content ($Mn_{max}$) in the space between dendrites. A value obtained by dividing the Mn content in the space between dendrites measured by linear analysis by an average Mn content in the slab was set as the value of F2.

[Microstructure Observation Method]

**[0073]** Each steel bar having a diameter of 35 mm was cut to have a cross section (transverse section) perpendicular to a longitudinal direction and including a center portion, and a test piece mirror polished and corroded by nital was randomly observed at 15 visual fields, from a region excluding a decarburized layer of a surface layer, at a magnification of 400 times using an optical microscope, to perform microstructure investigation. A size of each visual field is 250 μm × 250 μm.

[Manufacturing of Test Piece for Surface Fatigue Strength and Test Piece for Bending Fatigue Strength]

**[0074]** The machining of the round bar of each steel number having a diameter of 35 mm was performed to manufacture a roller pitching small roller test piece (hereinafter, simply referred to as a small roller test piece) shown in FIG. 1 and Ono-type rotating bending fatigue test piece with notches shown in FIG. 2 (in both FIG. 1 and FIG. 2, the unit for the dimensions in the drawings is mm). The small roller test piece shown in FIG. 1 includes a test portion (columnar portion having a diameter of 26 mm and a width of 28 mm) at the center.

**[0075]** Each test piece manufactured was subjected to carburizing hardening under the conditions shown in FIG. 3 using a gas carburizing furnace. After hardening, tempering was performed at 150°C for 1.5 hours. Finish machining of grip sections was performed with respect to the small roller test piece and the Ono-type rotating bending fatigue test piece with notches, in order to remove a strain due to heat treatment.

[Surface Fatigue Strength Test]

**[0076]** In the roller pitching test, the small roller test piece as described above and a large roller having a shape shown in FIG. 4 (the unit for the dimensions in the drawing is mm) was combined with each other. The large roller shown in FIG. 4 is formed of a steel satisfying the standards in JIS standard SCM420 (steel number 17) and was manufactured by typical manufacturing processes, that is, processes of normalizing, test piece processing, eutectoid carburizing using a gas carburizing furnace, low temperature tempering, and polishing.

**[0077]** The roller pitching test using the small roller test piece and the large roller was performed under the conditions shown in Table 2.

**[0078]** As shown in Table 2, a rotation speed of the small roller test piece was set as 1000 rpm, a slip ratio was set as -40%, contact surface pressure between the large roller and the small roller test piece during the test was set as 4000 MPa, and the number of cycles was set as $2.0\times10^7$ times. When a rotation speed of the large roller was set as V1 (m/sec) and a rotation speed of the small roller test piece was set as V2 (m/sec), the slip ratio (%) was acquired by the following expression.

$$\text{Slip ratio} = (V2-V1)/V2\times100$$

**[0079]** During the test, a lubricant (commercially available oil for automatic transmission) was sprayed onto a contact portion (surface of a test portion) between the large roller and the small roller test piece in a direction opposite to a rotation direction, under the condition of an oil temperature of 90°C. Under the conditions described above, the roller pitching test was performed and the surface fatigue strength was evaluated.

**[0080]** Regarding each steel number, the number of roller pitching tests was set as 6. After the test, an S-N diagram, in which a vertical axis indicates surface pressure and a horizontal axis indicates the number of cycles until the pitching is occurred, was drawn. Among the steels in which the pitching did not occur until the number of cycles became $2.0\times10^7$ times, the highest surface pressure was defined as surface fatigue strength of the corresponding steel number. Among the damaged portions on the surface of the small roller test piece, a case where the maximum area thereof is 1 $mm^2$ or greater was defined as the pitching is occurred.

**[0081]** Table 3 shows surface fatigue strength obtained by the test. In the surface fatigue strength in Table 3, surface fatigue strength of the steel number 16 which is obtained by carburizing of the steel 16 satisfying the standards of JIS standard SCr420H which is typical steel as general-purpose steel, was set as a reference value (100%). The surface fatigue strength of each test number is shown as a percentage (%) with respect to the reference value. When the surface fatigue strength is 120% or greater, it is determined that excellent surface fatigue strength is obtained.

[Wear resistance evaluation]

**[0082]** In the roller pitching test, the wear amount of a test portion of the small roller test piece when the number of cycles was $1.0\times10^6$ times, was measured. Specifically, the maximum height roughness (Rz) was acquired based on JIS B0601 (2001). A small Rz value indicates high wear resistance. In the measurement of the wear amount, a roughness meter was used. Table 3 shows the wear amounts. In the wear amounts in Table 3, the wear amount of the steel number

16 was set as a reference value (100%). The wear amount of each steel number was shown as a percentage (%) with respect to the reference value. When the wear amount is 80% or smaller, it is determined that excellent wear resistance is obtained.

[Bending Fatigue Strength Test]

**[0083]** The bending fatigue strength was acquired by an Ono-type rotary bending fatigue test. The number of tests in the Ono-type rotary bending fatigue test was set as 8 for each steel number. The test was performed by setting a rotation speed at the time of the test as 3000 rpm and other conditions as those of a normal method. Among the steels in which the fracture did not occur until the number of cycles became $1.0 \times 10^4$ times, the highest stress was defined as middle cycle rotary bending fatigue strength. In addition, among the steels in which the fracture did not occur until the number of cycles became $1.0 \times 10^7$ times, the highest stress was defined as high cycle rotary bending fatigue strength.

**[0084]** Middle cycle and high cycle rotary bending fatigue strength are shown in Table 3. In the bending fatigue strength of a middle cycle and a high cycle, bending fatigue strength of a middle cycle and a high cycle of the steel number 16 which is obtained by carburizing of the steel 16 satisfying the standards of JIS standard SCr420H which is typical steel as general-purpose steel, was set as a reference value (100%). The bending fatigue strength of a middle cycle and a high cycle of each steel number is shown as a percentage (%) with respect to the reference value. When the bending fatigue strength of both the middle cycle and the high cycle is 115% or greater, it is determined that excellent bending fatigue strength is obtained.

[Cutting Test]

**[0085]** A cutting test was performed and machinability was evaluated. A cutting test piece was obtained by the following method. A steel bar of each steel number having a diameter of 70 mm was heated at a heating temperature of 1250°C for 30 minutes. The heated steel bar was subjected to hot forging at a finish temperature of 950°C or higher to obtain a round steel having a diameter of 60 mm. A cutting test piece having a diameter of 55 mm and a length of 450 mm was obtained from this round steel by machining. Using the cutting test piece, the cutting test was performed under the following conditions.

Cutting Test (Turning)

**[0086]** Chip: property of substrate is P20 type grade of cemented carbide, no coating,
Conditions: circumferential speed of 200 m/min, sending of 0.30 mm/rev, cutting of 1.5 mm, watersoluble cutting oil is used
Measurement item: wear amount of main cutting edge for flank after cutting time of 10 minutes

**[0087]** The wear amount of main cutting edge obtained is shown in Table 3. In Table 3, the wear amount of main cutting edge of the steel number 17 satisfying the standards of JIS standard SCM420H which is typical steel as general-purpose steel, was set as a reference value (100%). The wear amount of main cutting edge of each steel number is shown as a percentage (%) with respect to the reference value. When the wear amount of main cutting edge is 70% or smaller which is the wear amount of main cutting edge of the steel number 16, it is determined that excellent machinability is obtained.

**[0088]** Table 3 shows the average cooling rate, the F2 value, whether or not cracks occurs during casting, the micro-structure, the middle cycle bending fatigue strength, the high cycle bending fatigue strength, the surface fatigue strength, the wear amount, and the wear amount of main cutting edge. Here, underlines in Table 3 mean that conditions of Expression (2) and the object of the present invention are not satisfied.

[Table 1]

| | STEEL | CHEMICAL COMPOSITION (mass%) REMAINDER: Fe AND IMPURITIES | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C | Si | Mn | P | S | Ni | Cr | Bi | Mo | Al | Nb | Ti | Cu | N | O | F1 VALUE |
| EXAMPLE | 1 | 0.22 | 0.31 | 0.81 | 0.014 | 0.013 | - | 1.65 | 0.0001 | 0.03 | 0.033 | - | 0.0020 | - | 0.0148 | 0.0012 | 1.71 |
| | 2 | 0.21 | 0.46 | 0.81 | 0.012 | 0.014 | - | 1.96 | 0.0030 | 0.00 | 0.034 | - | 0.0020 | - | 0.0154 | 0.0010 | 1.96 |
| | 3 | 0.21 | 0.59 | 0.82 | 0.013 | 0.013 | - | 1.68 | 0.0001 | 0.07 | 0.035 | - | 0.0010 | - | 0.0165 | 0.0012 | 1.82 |
| | 4 | 0.20 | 0.33 | 0.82 | 0.014 | 0.015 | - | 1.90 | 0.0010 | 0.05 | 0.030 | - | 0.0020 | - | 0.0151 | 0.0010 | 2.00 |
| | 5 | 0.21 | 0.36 | 0.79 | 0.015 | 0.013 | - | 1.60 | 0.0045 | 0.09 | 0.030 | 0.029 | 0.0010 | - | 0.0139 | 0.0011 | 1.78 |
| | 6 | 0.18 | 0.49 | 0.63 | 0.013 | 0.015 | - | 1.91 | 0.0030 | 0.09 | 0.031 | - | 0.0010 | - | 0.0182 | 0.0011 | 2.09 |
| | 7 | 0.22 | 0.51 | 0.75 | 0.011 | 0.014 | 0.12 | 2.00 | 0.0040 | 0.00 | 0.034 | - | 0.0010 | 0.05 | 0.0175 | 0.0009 | 2.00 |
| | 8 | 0.20 | 0.48 | 0.71 | 0.013 | 0.015 | - | 1.72 | 0.0050 | 0.07 | 0.035 | - | 0.0010 | - | 0.0155 | 0.0013 | 1.86 |
| | 9 | 0.21 | 0.36 | 0.69 | 0.012 | 0.013 | - | 1.89 | 0.0001 | 0.08 | 0.037 | - | 0.0020 | - | 0.0152 | 0.0011 | 2.05 |
| | 10 | 0.19 | 0.52 | 0.75 | 0.015 | 0.013 | 0.10 | 1.82 | 0.0050 | 0.09 | 0.034 | - | 0.0010 | - | 0.0162 | 0.0011 | 2.00 |
| | 11 | 0.21 | 0.35 | 0.80 | 0.012 | 0.013 | - | 1.61 | 0.0010 | 0.06 | 0.037 | - | 0.0020 | - | 0.0182 | 0.0009 | 1.73 |
| | 12 | 0.23 | 0.42 | 0.72 | 0.011 | 0.012 | - | 1.63 | 0.0002 | 0.04 | 0.038 | - | 0.0010 | - | 0.0176 | 0.0012 | 1.71 |
| | 13 | 0.19 | 0.37 | 0.45 | 0.013 | 0.013 | - | 1.92 | 0.0010 | 0.00 | 0.036 | - | 0.0020 | - | 0.0155 | 0.0010 | 1.92 |
| | 14 | 0.22 | 0.41 | 0.98 | 0.012 | 0.013 | - | 1.74 | 0.0050 | 0.00 | 0.031 | - | 0.0010 | - | 0.0149 | 0.0009 | 1.74 |
| | 15 | 0.21 | 0.41 | 0.81 | 0.012 | 0.014 | 0.11 | 1.98 | 0.0001 | 0.05 | 0.030 | - | 0.0011 | - | 0.0149 | 0.0009 | 2.08 |
| COMPARATIVE EXAMPLE | 16 | 0.21 | 0.21 | 0.86 | 0.012 | 0.013 | - | 1.08 | - | 0.00 | 0.029 | - | - | - | 0.0157 | 0.0012 | 1.08 |
| | 17 | 0.21 | 0.19 | 0.78 | 0.013 | 0.014 | - | 1.02 | - | 0.36 | 0.031 | - | - | - | 0.0161 | 0.0011 | 1.74 |
| | 18 | 0.19 | 0.39 | 1.12 | 0.015 | 0.013 | - | 1.90 | 0.0050 | 0.12 | 0.034 | 0.024 | 0.0011 | 0.12 | 0.0134 | 0.0008 | 2.14 |
| | 19 | 0.23 | 0.35 | 0.87 | 0.014 | 0.014 | - | 1.65 | 0.0002 | 0.27 | 0.024 | - | 0.0020 | - | 0.0126 | 0.0010 | 2.19 |
| | 20 | 0.19 | 0.46 | 1.32 | 0.013 | 0.013 | - | 1.48 | 0.0030 | 0.32 | 0.031 | - | 0.0010 | - | 0.0142 | 0.0018 | 2.12 |
| | 21 | 0.24 | 0.34 | 0.85 | 0.015 | 0.014 | - | 2.10 | 0.0001 | 0.04 | 0.035 | - | 0.0015 | - | 0.0125 | 0.0014 | 2.18 |
| | 22 | 0.23 | 0.56 | 0.86 | 0.014 | 0.014 | - | 1.65 | 0.0020 | 0.00 | 0.028 | - | 0.0002 | - | 0.0135 | 0.0016 | 1.65 |
| | 23 | 0.20 | 0.34 | 1.25 | 0.013 | 0.015 | - | 1.45 | 0.0050 | 0.11 | 0.033 | - | 0.0015 | 0.11 | 0.0142 | 0.0017 | 1.67 |
| | 24 | 0.21 | 0.12 | 1.64 | 0.015 | 0.013 | - | 1.92 | 0.0050 | 0.05 | 0.032 | - | 0.0013 | - | 0.0121 | 0.0009 | 2.02 |
| | 25 | 0.19 | 0.84 | 1.40 | 0.014 | 0.014 | - | 1.80 | 0.0010 | 0.08 | 0.032 | 0.005 | 0.0012 | - | 0.0123 | 0.0016 | 1.96 |
| | 26 | 0.21 | 0.65 | 1.64 | 0.015 | 0.013 | 0.12 | 1.85 | 0.0030 | 1.12 | 0.022 | - | 0.0020 | - | 0.0137 | 0.0012 | 4.09 |
| | 27 | 0.25 | 0.38 | 0.85 | 0.013 | 0.012 | - | 1.69 | - | 0.01 | 0.031 | - | 0.0015 | - | 0.0105 | 0.0015 | 1.71 |
| | 28 | 0.21 | 0.42 | 0.84 | 0.013 | 0.013 | - | 1.85 | - | 0.10 | 0.034 | - | 0.0020 | 0.06 | 0.0135 | 0.0016 | 2.05 |
| | 29 | 0.26 | 0.36 | 0.24 | 0.015 | 0.013 | 0.05 | 1.68 | 0.0020 | 0.07 | 0.025 | - | 0.0008 | - | 0.0145 | 0.0017 | 1.82 |
| | 30 | 0.22 | 0.49 | 1.32 | 0.016 | 0.014 | - | 1.86 | 0.0050 | 0.07 | 0.031 | - | 0.0020 | - | 0.0125 | 0.0009 | 2.00 |
| | 31 | 0.21 | 0.35 | 0.81 | 0.016 | 0.016 | - | 1.94 | 0.0070 | 0.05 | 0.031 | - | 0.0010 | - | 0.0122 | 0.0012 | 2.04 |
| | 32 | 0.23 | 0.41 | 0.75 | 0.015 | 0.014 | - | 1.96 | 0.0036 | 0.10 | 0.035 | - | 0.0020 | - | 0.0135 | 0.0012 | 2.16 |
| | 33 | 0.24 | 0.39 | 0.80 | 0.014 | 0.016 | - | 1.84 | 0.0035 | 0.02 | 0.026 | 0.002 | 0.0005 | - | 0.0124 | 0.0019 | 1.88 |
| | 34 | 0.19 | 0.46 | 0.75 | 0.016 | 0.015 | - | 1.86 | 0.0041 | 0.00 | 0.041 | - | 0.0010 | - | 0.0135 | 0.0009 | 1.86 |
| | 35 | 0.23 | 0.44 | 0.73 | 0.015 | 0.014 | - | 1.69 | 0.0030 | 0.01 | 0.069 | - | 0.0020 | - | 0.0112 | 0.0011 | 1.71 |

UNDERLINES INDICATE THAT THE VALUES ARE NOT IN THE CONDITIONS REGULATED IN THE PRESENT INVENTION.

[Table 2]

| | |
|---|---|
| TESTER | ROLLER PITCHING TESTER |
| TEST PIECE | SMALL ROLLER $\phi$26mm<br>LARGE ROLLER $\phi$130mm<br>(CONTACT PORTION: 700 mmR) |
| MAXIMUM SURFACE PRESSURE | 4000MPa |
| NUMBER OF TESTS | 6 |
| SLIP RATIO | -40% |
| SMALL ROLLER ROTATION SPEED | 1000rpm |
| CIRCUMFERENTIAL SPEED | SMALL ROLLER: 1.36 m/s, LARGE ROLLER: 1.90 m/s |
| TEMPERATURE OF LUBRICANT | 90° C |
| OIL USED | OIL FOR AUTOMATIC TRANSMISSION |

[Table 3]

| | STEEL NUMBER | AVERAGE COOLING RATE (°C/min) | PERCENTAGE OF Mn SEGREGATION F2 VALUE | WHETHER OR NOT SURFACE CRACKS OCCURRED DURING CASTING | MICROSTRUCTURE | MIDDLE CYCLE/ BENDING FATIGUE STRENGTH (STANDARDIZED) | HIGH CYCLE/ BENDING FATIGUE STRENGTH (STANDARDIZED) | SURFACE FATIGUE STRENGTH/ (STANDARDIZED) | WEAR AMOUNT/ (STANDARDIZED) | CUTTING TEST/ WEAR AMOUNT OF MAIN CUTTING EDGE (STANDARDIZED) |
|---|---|---|---|---|---|---|---|---|---|---|
| EXAMPLE | 1 | 240 | 1.44 | NOT OCCUR | F+P+B | 116 | 116 | 121 | 80 | 65 |
| | 2 | 210 | 1.16 | NOT OCCUR | F+P+B | 125 | 125 | 126 | 74 | 60 |
| | 3 | 300 | 1.44 | NOT OCCUR | F+P+B | 120 | 120 | 123 | 77 | 66 |
| | 4 | 260 | 1.25 | NOT OCCUR | F+P+B | 126 | 126 | 127 | 73 | 64 |
| | 5 | 405 | 1.12 | NOT OCCUR | F+P+B | 117 | 117 | 123 | 78 | 58 |
| | 6 | 180 | 1.16 | NOT OCCUR | F+P | 129 | 129 | 129 | 71 | 55 |
| | 7 | 200 | 1.13 | NOT OCCUR | F+P+B | 126 | 126 | 127 | 73 | 58 |
| | 8 | 490 | 1.12 | NOT OCCUR | F+P+B | 119 | 120 | 125 | 77 | 56 |
| | 9 | 320 | 1.44 | NOT OCCUR | F+P+B | 128 | 128 | 128 | 72 | 63 |
| | 10 | 260 | 1.12 | NOT OCCUR | F+P+B | 127 | 127 | 129 | 72 | 58 |
| | 11 | 300 | 1.25 | NOT OCCUR | F+P+B | 117 | 117 | 121 | 79 | 60 |
| | 12 | 260 | 1.39 | NOT OCCUR | F+P+B | 116 | 116 | 121 | 78 | 63 |
| | 13 | 200 | 1.25 | NOT OCCUR | F+P | 123 | 123 | 125 | 75 | 47 |
| | 14 | 400 | 1.12 | NOT OCCUR | F+P+B | 117 | 117 | 121 | 79 | 68 |
| | 15 | 160 | 1.44 | NOT OCCUR | F+P+B | 129 | 129 | 129 | 71 | 69 |
| COMPARATIVE EXAMPLE | 16 | 240 | 2.45 | NOT OCCUR | F+P | 100 | 100 | 100 | 100 | 70 |
| | 17 | 260 | 2.65 | NOT OCCUR | F+P+B | 117 | 117 | 121 | 79 | 100 |
| | 18 | 310 | 1.12 | NOT OCCUR | F+P+B | 132 | 132 | 132 | 70 | 75 |
| | 19 | 260 | 1.39 | NOT OCCUR | F+P+B | 133 | 133 | 131 | 68 | 74 |
| | 20 | 300 | 1.16 | NOT OCCUR | F+P+B | 132 | 132 | 131 | 70 | 79 |
| | 21 | 350 | 1.44 | NOT OCCUR | F+P+B | 132 | 132 | 131 | 69 | 75 |
| | 22 | 400 | 1.19 | NOT OCCUR | F+P | 110 | 110 | 115 | 81 | 60 |
| | 23 | 250 | 1.12 | NOT OCCUR | F+P | 113 | 113 | 115 | 81 | 68 |
| | 24 | 400 | 1.12 | NOT OCCUR | F+P+B | 128 | 129 | 111 | 72 | 86 |
| | 25 | 210 | 1.25 | NOT OCCUR | F+P+B | 125 | 125 | 126 | 74 | 83 |
| | 26 | 150 | 1.16 | NOT OCCUR | F+B | 200 | 201 | 176 | 25 | 120 |
| | 27 | 300 | 2.41 | NOT OCCUR | F+P+B | 116 | 116 | 121 | 80 | 82 |
| | 28 | 210 | 2.43 | NOT OCCUR | F+P+B | 125 | 125 | 126 | 74 | 87 |
| | 29 | 455 | 1.19 | NOT OCCUR | F+P+B | 100 | 100 | 105 | 82 | 65 |
| | 30 | 190 | 1.12 | NOT OCCUR | F+P+B | 105 | 105 | 115 | 85 | 76 |
| | 31 | 410 | 1.09 | OCCURRED | F+P+B | 127 | 127 | 128 | 72 | 59 |
| | 32 | 320 | 1.14 | NOT OCCUR | F+P+B | 132 | 132 | 131 | 69 | 72 |
| | 33 | 650 | 1.15 | OCCURRED | F+P+B | 122 | 122 | 124 | 76 | 59 |
| | 34 | 50 | 2.60 | NOT OCCUR | F+P+B | 121 | 121 | 124 | 76 | 75 |
| | 35 | 325 | 1.16 | NOT OCCUR | F+P+B | 105 | 105 | 121 | 80 | 55 |

REGARDING THE MIDDLE CYCLE BENDING FATIGUE STRENGTH, THE HIGH CYCLE BENDING FATIGUE STRENGTH, THE SURFACE FATIGUE STRENGTH, AND THE WEAR AMOUNT, THE VALUES THEREOF BASED ON JIS-SCr420 OF THE STEEL NUMBER 16 ARE SET AS 100 AND ARE STANDARDIZED.
REGARDING THE WEAR AMOUNT OF MAIN CUTTING EDGE, THE VALUE THEREOF BASED ON JIS-SCM420 IS SET AS 100 AND IS STANDARDIZED.
UNDERLINES INDICATE THAT THE VALUES ARE NOT IN THE CONDITIONS REGULATED IN THE PRESENT INVENTION.
UNDERLINES OF THE MIDDLE CYCLE BENDING FATIGUE STRENGTH INDICATE VALUES OF 115 OR SMALLER (STANDARDIZED).
UNDERLINES OF THE HIGH CYCLE BENDING FATIGUE STRENGTH INDICATE VALUES OF 115 OR SMALLER (STANDARDIZED).
UNDERLINES OF THE SURFACE FATIGUE STRENGTH INDICATE VALUES OF 120 OR SMALLER (STANDARDIZED).
UNDERLINES OF THE WEAR AMOUNT INDICATE VALUES EXCEEDING 80 (STANDARDIZED).
UNDERLINES OF THE WEAR AMOUNT OF MAIN CUTTING EDGE INDICATE VALUES OF 70% OR GREATER (STANDARDIZED).

**[0089]** With reference to Table 1 and Table 3, the chemical composition of the steels 1 to 15 were in the range of the chemical composition of the rolled steel bar or a bar or hot rolled wire rod for hot forging according to the embodiment, and Expression (1) and Expression (2) were satisfied. As a result, the steels 1 to 15 had excellent bending fatigue strength, surface fatigue strength, wear resistance, and machinability.

**[0090]** As shown in Table 3, the steel 16 is SCR 420 regulated based on JIS, and the amounts of Si and Cr and the values of F1 and F2 are out of the ranges of the present invention. The steel 17 is SCM 420 regulated based on JIS, and the amounts of Si, Cr, and Mo and the value of F2 are out of the ranges of the present invention. Therefore, any of the desired bending fatigue strength, surface fatigue strength, and machinability is not obtained.

**[0091]** In the steel 18, the Mn content and the Mo content exceeded the upper limits of the Mn content and the Mo content of the hot rolled bar or hot rolled wire rod according to the embodiment. Since the Mo content was large, the bending fatigue strength and the surface fatigue strength were equal to or higher than the regulation. However, since the value of F1 exceeded the upper limit of Expression (1) and Mn was excessively included, a lot of hard bainite was generated and machinability was deteriorated.

**[0092]** In the steel 19, the Mo content exceeded the upper limit of the Mo content of the hot rolled bar or hot rolled wire rod according to the embodiment and the Al content was equal to or less than the lower limit of the Al content thereof. The Al content was small and austenite grains were coarsened, but the Mo content was excessive, and a decrease in the bending fatigue strength was avoided. However, since the value of F1 exceeded the upper limit of Expression (1), machinability was deteriorated.

**[0093]** In the steel 20, the Cr content was lower than the Cr content of the hot rolled bar or hot rolled wire rod according to the embodiment, and the Mn content and the Mo content exceeded the upper limits of the Mn content and the Mo content thereof. Since the Mo content of the steel 20 was large, the bending fatigue strength and the surface fatigue strength were equal to or higher than the regulation. However, since the value of F1 exceeded the upper limit of Expression (1) and Mn was excessively included, a lot of hard bainite was generated and machinability was deteriorated. In the steel 21, the Cr content exceeded the upper limit of the Cr content of the hot rolled bar or hot rolled wire rod according to the embodiment. Accordingly, the value of F1 exceeded the upper limit of Expression (1), and machinability was deteriorated.

**[0094]** The chemical composition of the steel 22 were in the range of the chemical composition of the hot rolled bar or hot rolled wire rod according to the embodiment. However, the value of F1 of the steel 22 was lower than the lower limit of Expression (1), and fatigue strength was decreased.

**[0095]** In the steel 23, the Cr content was equal to or less than the lower limit of the Cr content of the hot rolled bar or hot rolled wire rod according to the embodiment and the Mn content and the Mo content exceeded the upper limits of the Mn content and the Mo content thereof. Although the Mo content was excessively included, the Cr content was equal to or less than the lower limit of the Cr content and the value of F1 was lower than the lower limit of Expression (1). Accordingly, as a result, the bending fatigue strength and the surface fatigue strength were decreased.

**[0096]** In the steel 24, the Si content was equal to or lower than the lower limit of the Si content of the hot rolled bar or hot rolled wire rod according to the embodiment and the Mn content exceeded the upper limit of the Mn content thereof. As a result, in the steel 24, the surface fatigue strength was decreased and the machinability was deteriorated.

**[0097]** In the steel 25, the Si content and the Mn content exceeded the upper limits of the Si content and the Mn content of the hot rolled bar or hot rolled wire rod according to the embodiment. As a result, in the steel 25, the machinability was deteriorated.

**[0098]** In the steel 26, the Si content, the Mo content, and the Mn content exceeded the upper limits of the Si content, the Mo content, and the Mn content of the hot rolled bar or hot rolled wire rod according to the embodiment and the Al content was equal to or lower than the lower limit of the Al content thereof. The Al content was small and austenite grains were coarsened, but the Mo content was excessive, and a decrease in the bending fatigue strength was avoided. However, since the value of F1 exceeded the upper limit of Expression (1), machinability was deteriorated.

**[0099]** The steel 27 and the steel 28 did not include Bi. The chemical composition thereof were in the range of the chemical composition of the hot rolled bar or hot rolled wire rod according to the embodiment, except for the Bi content, and Expression (1) was satisfied. However, the value exceeded the upper limit of Expression (2). As a result, the machinability was low. Specifically, it was assumed that, since Bi was not included, the microsegregation of Mn was large, hard bainite was generated, and machinability was deteriorated.

**[0100]** In the steel 29, the Mn content was equal to or less than the lower limit of the Mn content of the hot rolled bar or hot rolled wire rod according to the embodiment. As a result, the bending fatigue strength and the surface fatigue strength were decreased. It was considered that, since Mn content was small, core strength was insufficient and the bending fatigue strength and the surface fatigue strength were decreased.

**[0101]** In the steel 30, the Mn content exceeded the upper limit of the Mn content of the hot rolled bar or hot rolled wire rod according to the embodiment. As a result, bending fatigue strength, surface fatigue strength, wear resistance, and machinability were low. It was considered that, since Mn was excessively included, a depth of a carburized abnormal layer was increased, the bending fatigue strength and the surface fatigue strength were decreased, and also since Mn was excessively included, a lot of hard bainite was generated and machinability was deteriorated.

**[0102]** The steel 31 is an example in which the Bi content is more than the range regulated in the present invention. Accordingly, hot workability was deteriorated and cracks occurred during casting.

**[0103]** The chemical composition of the steel 32 was in the range of the chemical composition of the hot rolled bar or hot rolled wire rod according to the embodiment. However, since the value of F1 exceeded the upper limit of Expression (1), the machinability was deteriorated.

**[0104]** The chemical composition of the steel 33 was in the range of the chemical composition of the hot rolled bar or hot rolled wire rod according to the embodiment. However, since the average cooling rate is equal to or faster than the desired upper limit value thereof, the solidificated structure becomes uneven and cracks due to the uneven structure may occur. Accordingly, hot workability was deteriorated and cracks occurred.

**[0105]** The chemical composition of the steel 34 was in the range of the chemical composition of the hot rolled bar or hot rolled wire rod according to the embodiment. However, the average cooling rate was less than the lower limit thereof, and solidification was excessively slow. Accordingly, the space between dendrites was widened, and Mn was segregated. As a result, the value of F2 exceeded the upper limit of Expression (2) and the machinability was deteriorated.

**[0106]** In the steel 35, the Al content exceeded the upper limit of the Al content of the hot rolled bar or hot rolled wire rod according to the embodiment. As a result, coarse Al oxides were generated and the bending fatigue strength was decreased.

**[0107]** Hereinabove, the embodiments of the present invention have been described, but the embodiments described above are merely examples for achieving the present invention. Thus, the present invention is not limited to the embodiments and the present invention can be achieved with appropriate modifications of the embodiments described above within a range not departing from the gist thereof.

## Claims

1. A hot rolled bar or hot rolled wire rod comprising:

    a chemical composition including, by mass%,
    C: 0.05 to 0.30%,
    Si: 0.30 to 0.60%,
    Mn: 0.40 to 1.0%,
    S: 0.008 to less than 0.040%,
    Cr: 1.60 to 2.00%,
    Mo: 0 to 0.1% or less,
    Al: 0.025 to 0.05%,
    N: 0.010 to 0.025%,
    Ti: 0 to 0.003%,
    Bi: 0.0001 to 0.0050%,
    and a remainder including Fe and impurities,
    wherein amounts of P and O in the impurities are respectively
    P: 0.025% or less, and
    O: 0.002% or less;
    wherein a microstructure includes ferrite-pearlite or ferrite-pearlite-bainite, and an Expression (1) is satisfied,

$$1.70 \leq Cr + 2 \times Mo \leq 2.10 \ldots (1),$$

    where, an element symbol in the Expression (1) represents an amount of a corresponding element (mass%).

2. The hot rolled bar or hot rolled wire rod according to claim 1, comprising, instead of a part of Fe, by mass%,
Nb: 0.08% or less.

3. The hot rolled bar or hot rolled wire rod according to claim 1 or 2, comprising, instead of a part of Fe,
one or more elements selected from Cu: 0.40% or less and Ni: 0.80% or less.

4. A component obtained by cutting the hot rolled bar or hot rolled wire rod according to any one of claims 1 to 3.

5. A manufacturing method of a hot rolled bar or hot rolled wire rod, comprising:

    manufacturing a slab including a chemical composition according to any one of claims 1 to 3 by continuous casting or ingot casting, wherein a ratio of Mn contents ($Mn_{max}/Mn$) satisfies an Expression (2); and hot rolling the slab,

$$Mn_{max}/Mn<2.4 \ldots(2),$$

where, in the Expression (2), the $Mn_{max}$ represents a Mn content in a space between primary arms of a dendrite and the Mn represents a Mn content in a steel (mass%).

FIG. 1

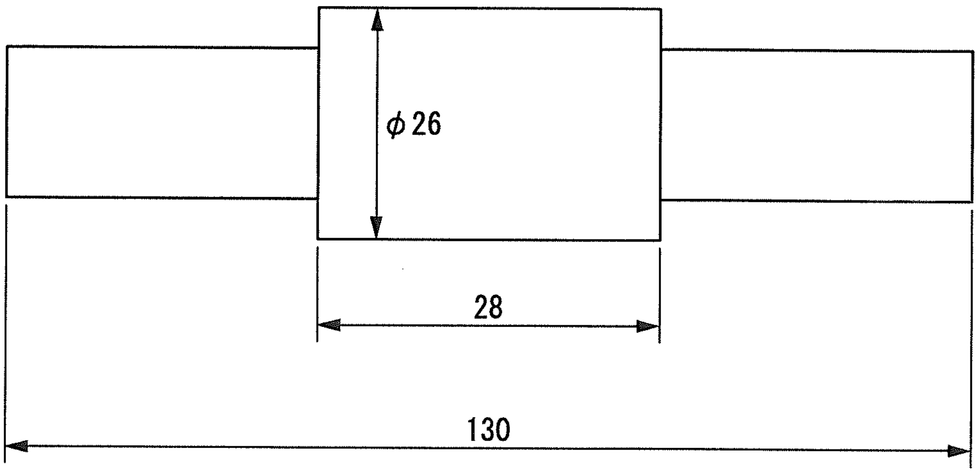



FIG. 2

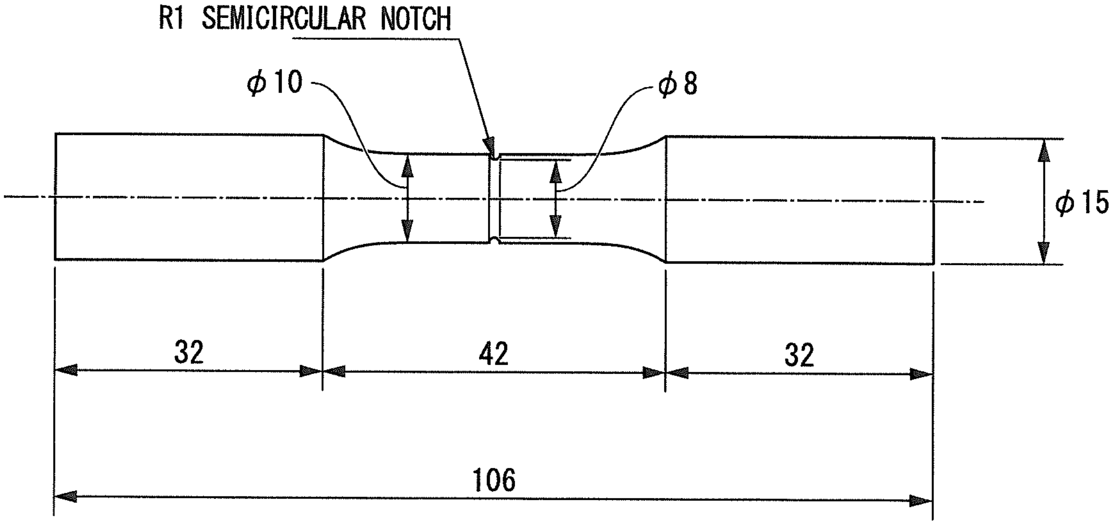


FIG. 3

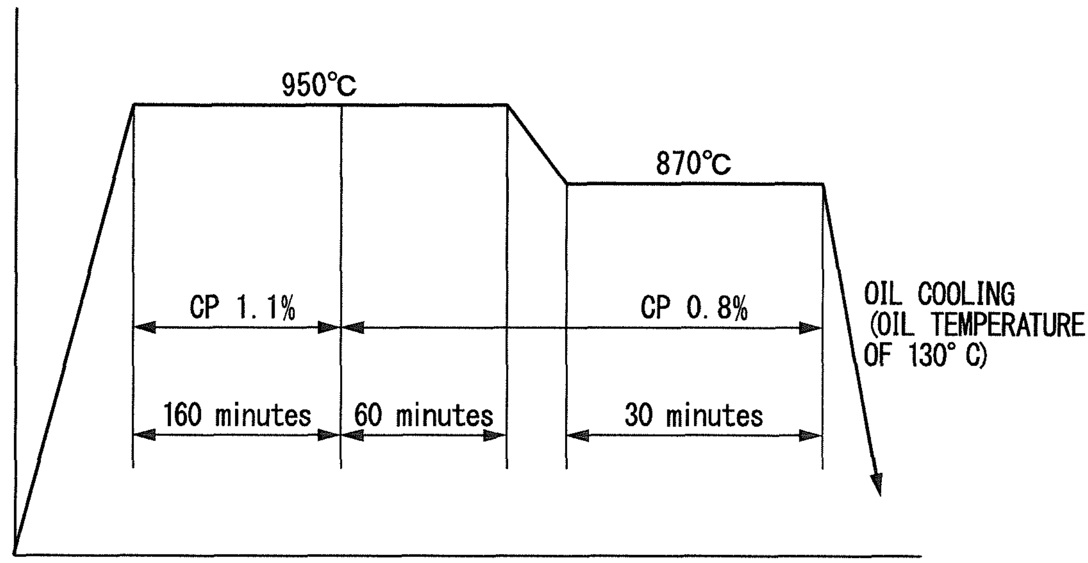
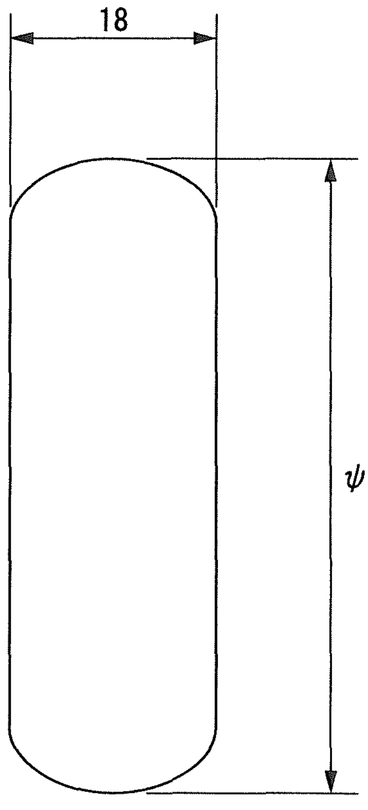

950℃
870℃
CP 1.1%
CP 0.8%
OIL COOLING
(OIL TEMPERATURE
OF 130° C)
160 minutes
60 minutes
30 minutes

FIG. 4


18
ψ130

## INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2016/061635

A. CLASSIFICATION OF SUBJECT MATTER
*C22C38/00*(2006.01)i, *B21B1/16*(2006.01)i, *C21D8/06*(2006.01)i, *C22C38/28*(2006.01)i, *C22C38/50*(2006.01)i

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, B21B1/16, C21D8/06, C22C38/28, C22C38/50

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 | 1996-2016 |
| Kokai Jitsuyo Shinan Koho | 1971-2016 | Toroku Jitsuyo Shinan Koho | 1994-2016 |

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y<br>A | WO 2013/031587 A1 (Nippon Steel & Sumitomo Metal Corp.),<br>07 March 2013 (07.03.2013),<br>paragraphs [0011], [0059] to [0116]; tables 1 to 6<br>& US 2014/0363329 A1<br>paragraphs [0011], [0067] to [0126]; tables 1 to 6<br>& CN 103797144 A & KR 10-2014-0056378 A<br>& IN 201402151 P1 | 1-4<br>5 |
| Y<br>A | JP 2007-197784 A (Daido Steel Co., Ltd.),<br>09 August 2007 (09.08.2007),<br>claims 1 to 5; paragraph [0026]; table 1<br>(Family: none) | 1-4<br>5 |

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 14 July 2016 (14.07.16) | 26 July 2016 (26.07.16) |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| Japan Patent Office<br>3-4-3,Kasumigaseki,Chiyoda-ku,<br>Tokyo 100-8915,Japan | Telephone No. |

**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/JP2016/061635

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y<br>A | JP 2011-157597 A (Sumitomo Metal Industries, Ltd.), 18 August 2011 (18.08.2011), claims 1 to 3; paragraph [0069] (Family: none) | 1-4<br>5 |
| A | JP 2011-99149 A (Sumitomo Metal Industries, Ltd.), 19 May 2011 (19.05.2011), (Family: none) | 1-5 |
| A | JP 2015-7278 A (Nippon Steel & Sumitomo Metal Corp.), 15 January 2015 (15.01.2015), (Family: none) | 1-5 |
| A | JP 2007-154290 A (Sumitomo Metal Industries, Ltd.), 21 June 2007 (21.06.2007), (Family: none) | 1-5 |
| A | JP 2004-18879 A (Kobe Steel, Ltd.), 22 January 2004 (22.01.2004), (Family: none) | 1-5 |

Form PCT/ISA/210 (continuation of second sheet) (January 2015)

## REFERENCES CITED IN THE DESCRIPTION

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### Patent documents cited in the description


- JP 2015071714 A **[0002]**
- JP S6021359 B **[0011]**
- JP H7242994 B **[0011]**
- JP H7126803 B **[0011]**
- JP 5114689 B **[0011]**
- JP 5561436 B **[0011]**
- JP H10259450 B **[0011]**