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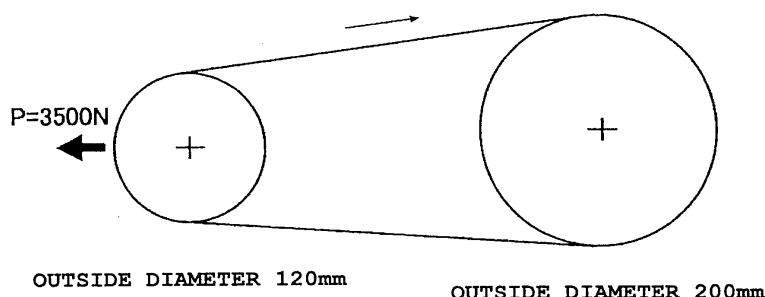
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(54) **STEEL FOR MECHANICAL STRUCTURE EXCELLING IN STRENGTH, DUCTILITY AND TOUGHNESS AND PROCESS FOR PRODUCING THE SAME**

(57) A steel for machine structural use with a better strength-ductility-toughness balance than maraging steel and applications thereof are provided. The steel for machine structural use with excellent strength, ductility, and toughness contains, in percent by mass, more than 0.30% to 0.5% of carbon, 1.0% or less of silicon, 1.5% or less of manganese, 0.025% or less of aluminum, 0.3% to 0.5% of molybdenum, and 0.0005% to 0.01% of boron,

and the balance is iron and incidental impurities. The steel has a structure including at least 90% by volume of martensitic structure. The martensitic structure includes blocks having a size of 1.5 μm or less. Dissolved boron is contained in an amount of at least 0.0005% and is present at boundaries of prior austenite grains in a concentration at least 1.5 times that in the prior austenite grains.

FIG. 1



Description

Technical Field

[0001] The present invention relates generally to steels for machine structural use, including components of automobiles and industrial machines. In particular, the present invention relates to steels for machine structural use which have excellent strength, ductility, and toughness and are particularly suitable for metal belts, for example, used in continuously variable transmission (hereinafter abbreviated as CVT), which are currently produced with expensive steels such as maraging steel. The present invention also relates to steel sheets for machine structural use and metal belts produced with such steels.

Background Art

[0002] In the field of automobiles, higher fuel efficiency and emission control have recently been demanded with the growing awareness of environmental issues. Accordingly, developments have been directed toward miniaturized, high-powered driving systems. For example, the development of CVT is remarkable. Metals belts used for CVT require high strength, high ductility, and high toughness. Maraging steel is one of the steels currently used for such applications. Techniques using maraging steel are disclosed in, for example, Patent Documents 1 to 3. On the other hand, techniques using metastable austenitic stainless steel are disclosed in, for example, Patent Documents 4 and 5.

[0003] In general, however, alloying elements are added to materials requiring higher strength, including the steels described above. Maraging steel contains, for example, cobalt, molybdenum, and chromium in addition to ten and several percent of nickel while metastable austenitic stainless steel contains chromium and nickel in amounts of ten and several percent. Such steels are significantly costly, and the production thereof can be threatened by the recent shortage of materials.

Patent Document 1: Japanese Unexamined Patent Application Publication No. 2000-345302
 Patent Document 2: Japanese Unexamined Patent Application Publication No. 2002-38251
 Patent Document 3: Japanese Unexamined Patent Application Publication No. 2003-231921
 Patent Document 4: Japanese Unexamined Patent Application Publication No. 2002-53936
 Patent Document 5: Japanese Unexamined Patent Application Publication No. 2003-33803

Disclosure of Invention

[0004] In light of the above problems of the related art, an object of the present invention is to provide a steel and steel sheet for machine structural use which have high strength, high ductility, and high toughness with a minimal increase in production costs, and also provide a metal belt suitable as an endless metal belt for CVT at low cost.

[0005] As a result of intensive studies to achieve the above object, the inventors have found a solution to the above problems. That is, the inventors have demonstrated that even a steel system that does not contain such a large amount of nickel or chromium as contained in maraging steel and austenitic stainless steel provides a better balance between tensile strength and elongation and higher toughness than maraging steel if the steel contains appropriate amounts of molybdenum and boron and is quenched and tempered to form a martensitic structure.

[0006] Further studies on detailed structures constituting the martensitic structure (hereinafter referred to as substructures) have found that an especially excellent strength-elongation balance can be achieved by controlling blocks constituting the martensitic structure to a predetermined size or less. These studies have also found that excellent toughness can be ensured if dissolved boron is contained in at least a predetermined amount and is present at boundaries of prior austenite grains in a concentration at least 1.5 times that in the prior austenite grains.

[0007] The present invention, which has been completed depending on the above findings, can be summarized as follows:

(1) A steel for machine structural use with excellent strength, ductility, and toughness according to the present invention contains, in percent by mass, more than 0.30% to 0.5% of carbon, 1.0% or less of silicon, 1.5% or less of manganese, 0.025% or less of aluminum, 0.3% to 0.5% of molybdenum, and 0.0005% to 0.01% of boron, and the balance is iron and incidental impurities. The steel has a tensile strength of 2,000 MPa or more and a total elongation of 10% or more.

(2) The steel according to Item (1) further contains, in percent by mass, at least one of 2.5% or less of chromium, 1.0% or less of copper, 2.0% or less of nickel, and 0.5% or less of vanadium.

(3) The steel according to Item (1) or (2) further contains, in percent by mass, at least one of 0.1% or less of titanium and 0.1% or less of niobium.

(4) A steel for machine structural use with excellent strength, ductility, and toughness according to the present

invention contains, in percent by mass, more than 0.30% to 0.5% of carbon, 1.0% or less of silicon, 1.5% or less of manganese, 0.025% or less of aluminum, 0.3% to 0.5% of molybdenum, and 0.0005% to 0.01% of boron, and the balance is iron and incidental impurities. The steel has a structure including at least 90% by volume of martensitic structure. The martensitic structure includes blocks having a size of 1.5 μm or less. Dissolved boron is contained in an amount of at least 0.0005% and is present at boundaries of prior austenite grains in a concentration at least 1.5 times that in the prior austenite grains.

(5) The steel according to Item (4) further contains, in percent by mass, at least one of 2.5% or less of chromium, 1.0% or less of copper, 2.0% or less of nickel, and 0.5% or less of vanadium.

(6) The steel according to Item (4) or (5) further contains, in percent by mass, at least one of 0.1% or less of titanium and 0.1% or less of niobium.

(7) A steel sheet for machine structural use with excellent strength, ductility, and toughness according to the present invention is formed of the steel for machine structural use according to one of Items (1) to (6) and has a thickness of 0.5 mm or less.

(8) A metal belt according to the present invention is formed of the steel sheet according to Item (7) and has an annular shape.

(9) A method for producing a steel for machine structural use with excellent strength, ductility, and toughness according to the present invention includes quenching a steel material by heating at a rate of temperature rise of 100°C/s or more and tempering the steel material at 100°C to 400°C. The steel material contains, in percent by mass, more than 0.30% to 0.5% of carbon, 1.0% or less of silicon, 1.5% or less of manganese, 0.025% or less of aluminum, 0.3% to 0.5% of molybdenum, and 0.0005% to 0.01% of boron, and the balance is iron and incidental impurities.

(10) In Item (9), the steel material further contains, in percent by mass, at least one of 2.5% or less of chromium, 1.0% or less of copper, 2.0% or less of nickel, and 0.5% or less of vanadium.

(11) In Item (9) or (10), the steel material further contains, in percent by mass, at least one of 0.1% or less of titanium and 0.1% or less of niobium.

(12) A method for producing a steel sheet for machine structural use with excellent strength, ductility, and toughness according to the present invention includes quenching a steel sheet by heating at a rate of temperature rise of 100°C/s or more and tempering the steel sheet at 100°C to 400°C. The steel sheet contains, in percent by mass, more than 0.30% to 0.5% of carbon, 1.0% or less of silicon, 1.5% or less of manganese, 0.025% or less of aluminum, 0.3% to 0.5% of molybdenum, and 0.0005% to 0.01% of boron, and the balance is iron and incidental impurities. The steel sheet has a thickness of 0.5 mm or less.

(13) In Item (12), the steel sheet further contains, in percent by mass, at least one of 2.5% or less of chromium, 1.0% or less of copper, 2.0% or less of nickel, and 0.5% or less of vanadium.

(14) In Item (12) or (13), the steel sheet further contains, in percent by mass, at least one of 0.1% or less of titanium and 0.1% or less of niobium.

(15) A method for producing a metal belt according to the present invention includes quenching a metal belt by heating at a rate of temperature rise of 100°C/s or more and tempering the metal belt at 100°C to 400°C. The metal belt contains, in percent by mass, more than 0.30% to 0.5% of carbon, 1.0% or less of silicon, 1.5% or less of manganese, 0.025% or less of aluminum, 0.3% to 0.5% of molybdenum, and 0.0005% to 0.01% of boron, and the balance is iron and incidental impurities. The metal belt has a thickness of 0.5 mm or less and has an annular shape.

(16) In Item (15), the metal belt further contains, in percent by mass, at least one of 2.5% or less of chromium, 1.0% or less of copper, 2.0% or less of nickel, and 0.5% or less of vanadium.

(17) In Item (15) or (16), the metal belt further contains, in percent by mass, at least one of 0.1% or less of titanium and 0.1% or less of niobium.

[0008] The present invention can provide a steel for machine structural use which has excellent strength, ductility, and toughness without containing large quantities of expensive alloying elements, a metal sheet for machine structural use produced with the steel, and a metal belt produced with the metal sheet.

Brief Description of the Drawings

[0009]

Fig. 1 is a diagram illustrating a method for a fatigue evaluation test with an endless metal belt.

Best Mode for Carrying Out the Invention

[0010] The composition, structure, strength, and elongation of the steel according to the present invention will now

be described in detail.

1. Composition

- 5 **[0011]** The reasons for the specified composition will be described. The contents (%) of the individual elements in the composition are all expressed in percent by mass.

Carbon: more than 0.30% to 0.5%

10 Carbon is an element essential for ensuring required strength and toughness. If the carbon content is not more than 0.30%, a predetermined strength is difficult to ensure. The upper limit is 0.5% because more than 0.5% of carbon decreases ductility and toughness and promotes formation of huge carbide grains in the structure of the steel, which significantly degrade fatigue properties.

Silicon: 1.0% or less

15 The steel can contain silicon because it serves as a deoxidant during the production of the steel. The upper limit is 1.0% because more than 1.0% of silicon significantly decreases the ductility of the steel.

Manganese: 1.5% or less

The steel can contain manganese because it serves as a deoxidant during the production of the steel. The upper limit is 1.5% because more than 1.5% of manganese significantly decreases the ductility of the steel.

Aluminum: 0.025% or less

20 Aluminum is an element effective for deoxidation. In addition, aluminum is an element effective to maintain strength and toughness because it inhibits growth of austenite grains during quenching. The aluminum content, however, is limited to the above range because an aluminum content exceeding 0.025% results in a saturated effect and the disadvantage of increased costs.

Molybdenum: 0.3% to 0.5%

25 Molybdenum, a particularly important element in the present invention, increases strength and toughness without significantly decreasing ductility. Addition of 0.3% or more of molybdenum is required to realize its effect. The upper limit is 0.5% because addition of more than 0.5% of manganese does not contribute to a further increase in strength and toughness and results in increased costs. Also, the addition of an excessive amount of manganese decreases ductility.

30 Boron: 0.0005% to 0.01%

Boron is a useful element effective to improve quenching properties and provides grain boundary strengthening, which contributes to an increase in the strength of the entire steel. A boron content of 0.0005% or more is required to realize its effect. The boron content, however, is limited to the above range because a boron content exceeding 0.01% results in a saturated effect.

- 35 **[0012]** The above elements are basic components of the steel according to the present invention. In addition to these components, the steel can optionally contain the following elements:

Chromium: 2.5% or less

40 Chromium is effective to improve quenching properties and is useful to ensure hardening depth. An excessive content of chromium, however, promotes formation of carbide residues by a carbide stabilization effect, thus decreasing strength. Thus, a minimal content of chromium is preferred, although a chromium content of up to 2.5% is acceptable. A chromium content of 0.2% or more is preferred to realize the effect of improving quenching properties.

Copper: 1.0% or less

45 Copper is effective to improve quenching properties, and also increases strength when dissolved in ferrite. If the copper content exceeds 1.0%, the steel can be cracked during hot rolling. Thus, the copper content is limited to the above range. A copper content of 0.2% or more is preferred to realize the effect of improving quenching properties and strength.

Nickel: 2.0% or less

50 Nickel is effective to improve quenching properties, and also contributes to an increase in strength and toughness because it can inhibit growth of carbides and formation of carbide films at grain boundaries to increase grain boundary strength. However, nickel is an extremely expensive element, and addition of more than 2.0% of nickel significantly increases steel costs. Hence, the nickel content is preferably limited to 2.0% or less. A nickel content of 0.5% or more is preferred to realize the effect of improving quenching properties, strength, and toughness.

55 Vanadium: 0.5% or less

Vanadium can be expected to serve as a strengthening element by combining with carbon in the steel. Vanadium also has the effect of increasing softening resistance in tempering, thus contributing to increased strength. The vanadium content is limited to the above range because a vanadium content exceeding 0.5% results in a saturated

effect. A vanadium content of 0.1% or more is preferred to realize the effect of increasing strength.

[0013] The steel according to the present invention can further contain at least one of the following components:

5 Titanium: 0.1% or less

Titanium combines with nitrogen, contained as an incidental impurity, to prevent formation of BN. This avoids attenuation of the effect of boron, that is, improving quenching properties. The titanium content is preferably limited to 0.1% or less because a titanium content exceeding 0.1% results in formation of a large quantity of TiN, which decreases strength and fatigue strength. A titanium content of 0.005% or more is preferred to realize its effect.

10 Niobium: 0.1% or less

Niobium has the effect of improving quenching properties and also serves as a precipitation strengthening element to contribute to increased strength and toughness. The niobium content is preferably limited to 0.1% or less because a niobium content exceeding 0.1% results in a saturated effect. A niobium content of 0.005% or more is preferred to realize its effect.

15 **[0014]** The balance of the steel, other than the elements described above, is iron and incidental impurities. Typical incidental impurities include sulfur, phosphorus, nitrogen, and oxygen, which can be contained in amounts of up to 0.05%, up to 0.05%, up to 0.01%, and up to 0.01%, respectively.

20 2. Structure

[0015] While the preferred ranges of composition have been described above, only the limitation of the composition to the above ranges is insufficient in the present invention, and the structure of the steel must also be controlled as follows:

25 Steel structure: at least 90% by volume of martensitic structure

Martensite is a structure essential to achieve strength. The steel according to the present invention provides excellent properties if it contains at least 90% by volume of martensitic structure. Accordingly, the volume percentage of martensitic structure is limited to the above range. If the volume percentage of martensite falls below 90%, the steel contains excessive quantities of untransformed phases such as residual austenitic phase and precipitates such as carbides, which do not contribute to increased strength. This makes it difficult to achieve high strength, namely, 30 2,000 MPa or more.

Martensitic structure: the structure includes blocks having a size of 1.5 μm or less

A finer martensitic structure is preferred in terms of, for example, fatigue resistance. The martensitic structure, which is a typical structure transformed from austenite, has complicated substructures divided generally into the following structure units: martensite laths, the smallest unit, which have only slight differences in crystal orientation from adjacent ones and thus have no dominant effect on mechanical properties; blocks, groups of adjacent laths with substantially equivalent crystal planes and orientations, several blocks being contained in each austenite grain before transformation; and packets, groups of blocks with equivalent crystal planes but different growth directions. Formation of a finer martensitic structure substantially means formation of smaller structure units. Most effectively, this can be achieved by forming finer blocks. Martensite laths in blocks can be assumed as substantially continuous structures with low-angle tilt grain boundaries. On the other hand, the sizes of blocks, packets, and austenite grains before transformation probably have a direct effect on the mechanical properties of the material because of high-angle tilt grain boundaries. The size of blocks can be evaluated by, for example, orientation imaging microscopy or transmission electron microscopy (TEM). Although packets are another substructure unit of martensitic structure, the size of packets is preferably controlled with a structure unit smaller than packets with high-angle tilt grain boundaries, namely, blocks. It is not practical in actual processes to check all products for the size of austenitic structure before transformation before final heat treatment. Hence, the size of blocks in the martensitic structure should be controlled because they constitute a substructure which can readily be evaluated for final products (particularly, after the final heat treatment) and which affects the mechanical properties of the material. The steel according to the present invention provides a particularly excellent strength-ductility balance and toughness if the blocks have an average size of 1.5 μm or less. The term "size" used herein means an average grain size generally used for evaluation of steel structure. For example, an average grain size determined by an intercept method can be used.

55 **[0016]** Distribution of dissolved boron: dissolved boron is contained in the steel in an amount of at least 0.0005% and is present at boundaries of prior austenite grains in a concentration at least 1.5 times that in the grains after, for example, quenching

[0017] The steel according to the present invention provides stable mechanical properties if the distribution of dissolved boron is controlled as described below. In the present invention, as described above, the content of boron is specified

for obtaining improved quenching properties and grain boundary strengthening. A sufficient amount of dissolved boron and the distribution thereof is very important to realize the effect of boron. The amount of boron dissolved in the steel is decreased with, for example, formation of BN and $M_{23}(C,B)_6$ (where M is a metal element). Addition of an element that combines readily with nitrogen, such as titanium, is effective to inhibit the formation of BN. In a carbon-rich steel system, however, the added element is dissolved in carbides by substitution and thus fails to provide the expected effect. Accordingly, sufficient dissolution in the γ range is essential. In addition, the dissolved boron is preferably present mainly at boundaries of prior austenite grains. Grain boundary strength, which significantly affects mechanical properties including strength, elongation, and toughness, is increased if the dissolved boron is present mainly at boundaries of prior austenite grains with a difference in concentration from the interior of the grains (i.e., grain boundary segregation). The grain boundary segregation of the dissolved boron will prevent grain boundary segregation of phosphorus, which could cause grain boundary embrittlement. The studies by the inventors have confirmed that the steel can more reliably achieve stable toughness if the dissolved boron is contained in an amount of at least 0.0005% after final heat treatment, such as high-frequency heating quenching or low-temperature tempering at 400°C or less, and is present at boundaries of prior austenite grains in a concentration 1.5 times that in the prior austenite grains after the final heat treatment.

[0018] The amount of dissolved boron can be determined by subtracting the amount of precipitated boron from the amount of boron added. The amount of precipitated boron is determined by extracting and separating boron-containing precipitates occurring as oxides, nitrides, carbides, or intermetallic compounds through electrolysis, for example, and directly measuring the content of boron in the precipitates. The concentration distribution of dissolved boron in and at boundaries of prior austenite grains can be determined by, for example, secondary ion mass spectrometry (SIMS) to confirm that the ionic strength of the boundaries of the prior austenite grains is at least 1.5 times that of the interior of the grains if the grains have a grain size of 10 μm or more. Other effective means for high-sensitivity detection include determination of an electron energy loss spectrum (EELS) of grain boundaries by TEM and α -ray track etching (ATE), in which a film is irradiated with α rays emitted from a boron isotope with a mass number of 10 (B_{10}) by radioactivation of a sample in, for example, a nuclear reactor, although SIMS is the most suitable in terms of detection sensitivity and quantitative determination for a trace amount of boron. As described above, grain boundary embrittlement can be avoided if the dissolved boron is contained in an amount of at least 0.0005% and is present mainly at boundaries of prior austenite grains.

3. Strength and elongation

Tensile strength: 2,000 MPa or more; total elongation: 10% or more

[0019] The strength and total elongation of the steel according to the present invention are limited to the above ranges because the steel requires at least such strength and ductility levels to achieve properties comparable to those of maraging steel, a currently expensive steel intended to be replaced with the steel according to the present invention. If the steel has the composition and structure described above, it can achieve a tensile strength of 2,000 MPa or more, a total elongation of 10% or more, and high toughness. The studies by the inventors have also demonstrated that a metal belt for CVT produced with a steel having the above composition, a tensile strength of 2,000 MPa or more, and a total elongation of 10% or more has durability comparable to that of a metal belt produced with a conventional maraging steel.

[0020] Next, a method for producing a steel for machine structural use according to the present invention will be described. The steel is produced by quenching and tempering a steel material having the above composition. The rate of temperature rise in quenching and tempering temperature, which are important in the present invention, must be controlled as follows:

Rate of temperature rise in heating for quenching: 100°C/s or more

[0021] If the rate of temperature rise in heating for quenching falls below 100°C/s, the blocks of martensitic structure grow to a size exceeding 1.5 μm . In this case, the steel cannot have a good strength-ductility balance. Hence, the rate of temperature rise in heating for quenching must be 100°C/s or more.

Tempering temperature: 100°C to 400°C

[0022] If the tempering temperature falls within the range of 100°C to 400°C, the boron contained in the steel is concentrated at the grain boundaries without diffusion or precipitation, thus contributing to grain boundary strengthening. If the tempering temperature is 400°C or less, the steel maintains its high strength, high ductility, and high toughness in synergy with a fine grain effect. Excessive tempering temperatures result in decreased strength and decreased concentration of boron at the grain boundaries, thus significantly decreasing toughness. From this viewpoint, the tempering temperature must be 400°C or less. If the tempering temperature is less than 100°C, the steel exhibits insufficient

elongation and fails to provide a total elongation of 10% or more. Accordingly, the tempering temperature should fall within the range of 100°C to 400°C.

[0023] The steel material used can be one prepared by subjecting a steel ingot with the above composition to hot or cold working, such as rolling or forging. The steel ingot with the above composition can be one produced by converter melting or vacuum melting. In particular, if the steel material used is a steel sheet, a steel ingot or a continuously cast slab is subjected to hot rolling with heating, scale removal by pickling, and cold rolling to produce a steel sheet with a predetermined thickness. If a metal belt is to be produced with the steel sheet, the sheet is cold-rolled to a thickness of 0.5 mm or less, is cut into a predetermined width and length, and is formed into an annular shape to produce a metal belt.

[0024] The above steel material (including a steel sheet and a metal belt) is subjected to quenching and tempering to form a martensitic structure. The heating means used for these treatments can be high-frequency heating, furnace heating, infrared heating, or electrical heating.

[0025] The steel thus produced (including a steel sheet and a metal belt) has a strength-ductility balance comparable to that of maraging steel despite low production costs and can be used for automobile parts requiring high strength, high ductility, and high toughness. In particular, a metal belt produced with the steel is suitable for use as an endless metal belt for CVT, which is currently produced with maraging steel.

Examples

Example 1

[0026] Examples will now be described.

[0027] Steels shown in Table 1 were produced by vacuum melting. These steels were heated to 1,100°C and were hot-rolled into sheets with a thickness of 3 mm. These sheets were pickled to remove surface scale and were cold-rolled. The rolling was repeated many times. After the sheets were rolled to a thickness of 0.8 mm, they were annealed to remove work strain and were further cold-rolled to a final thickness of 0.4 mm. These materials were subjected to heat treatment and evaluation described below.

[0028] The structures of the steels, which are to be subjected to high-frequency heating quenching, after the final heat treatment are expected to contain only a martensitic phase formed by transformation from the austenite temperature range, an untransformed ferrite phase that can result from insufficient heating, and undissolved inclusions and precipitates such as carbides. These phases can be discriminated by developing the structures by nital etching, one of the generally used methods, and observing them using an optical microscope. Accordingly, the volume percentage of martensitic structure was determined by the method described below. The above materials were cut to a size of 20 mm x 20 mm, were heated to 920°C by high-frequency heating, were quickly quenched, and were tempered at 170°C for 20 minutes to prepare samples. The surfaces of the samples were etched with nital and were observed using an optical microscope to determine the area percentage of the region of phases other than martensitic phase which were discriminated by optical microscopy (i.e., untransformed ferrite phase and undissolved inclusions and precipitates such as carbides). The volume percentage of martensitic phase in the examples was determined by converting the area percentage of the region of the phases other than the martensitic phase to volume percentage and subtracting it from 100%. In the invention examples, the martensitic phase accounted for most of the structure because the temperature for high-frequency quenching was 920°C, which falls within the austenite range.

[0029] Blocks, one of the substructures of martensitic structure, were evaluated by the method described below. The above materials were cut into samples with a size of 20 mm x 20 mm. These samples were heated to 920°C by high-frequency heating, were quickly quenched, and were tempered at 170°C for 20 minutes. Subsequently, the samples were cut into samples for microscopy with a size of 10 mm x 10 mm. These samples were evaluated for blocks by orientation imaging microscopy.

[0030] Crystal orientation information was obtained at a total of about 11,000 points in two fields of view of 10 μm x 10 μm regions on each sample. In each field of view, the boundaries of closed regions of the same colors were recognized as blocks. The size of the blocks in the field of view was determined by the same intercept method as generally used for determination of average grain size. The simple arithmetic average of all measurements of the fields of view was determined as the average size of the blocks of the material.

[0031] The content of dissolved boron in each steel was determined by subtracting the amount of precipitated boron from the amount of boron added. The amount of precipitated boron was determined by electrolytic extraction analysis. First, the above materials were cut into samples with a size of 30 mm x 30 mm. These samples were heated to 920°C by high-frequency heating, were quickly quenched, and were tempered at 170°C for 20 minutes. Subsequently, 1 g of each tempered sample was electrolyzed in a 10% acetylacetone electrolytic solution, and electrolysis residues were filtered out to determine the amount of precipitated boron.

[0032] The concentration distribution of dissolved boron in each sample was measured by the method described below. The samples with a size of 10 mm x 10 mm used in the evaluation of block size were mirror-polished again for

concentration distribution measurement by SIMS. In the measurement by SIMS, the primary ions O_2^+ were used to obtain two fields of view of ion images of the secondary ions BO_2^- with a mass number of 43 from regions with a field stop of 150 μm (in diameter). Average secondary ion strengths at boundaries of grains and in the interior of the grains in each field of view were determined, and the ratio therebetween was determined. Finally, the arithmetic average of the ion strength ratios of the two fields of view was determined as the concentration distribution ratio of the sample.

[0033] Boundaries of prior austenite grains were inspected as follows. The samples with a size of 10 mm x 10 mm used in the measurement of concentration distribution of dissolved boron were used as samples for microscopy. L-shaped cross sections, parallel to the rolling direction, of the samples used in the measurement of concentration distribution of dissolved boron were mirror-polished and were exposed to an etchant to develop boundaries of prior austenite grains. The etchant was prepared by dissolving 50 g of picric acid in 500 g of water and adding 11 g of sodium dodecylbenzenesulfonate, 1 g of ferrous chloride, and 1.5 g of oxalic acid to the picric acid aqueous solution. The boundaries of prior austenite grains were inspected using an optical microscope at a magnification of x1,000.

[0034] The materials were cut into tensile test pieces (JIS No. 5) by electrical discharge machining. The test pieces were heated to 920°C by high-frequency heating, were quickly quenched, and were tempered at 170°C for 20 minutes. The test pieces were subjected to a tensile test.

[0035] Similarly, a maraging steel (Fe-18Ni-10Co-5Mo-0.4Ti) was processed until cold rolling and was cut into a test piece with the same shape as above. The test piece was heated to 820°C, was quenched by air cooling, and was subjected to aging by heating being to 520°C.

[0036] In evaluation of toughness, unlike the above, the steels were hot-rolled to a thickness of 15 mm and were cut into charpy test pieces with U-notches extending in the C direction of the rolled sheets. The test pieces were heated to 920°C by high-frequency heating, were quickly quenched, and were tempered at 170°C for 30 minutes. The test pieces were subjected to a charpy test, which was conducted under two different conditions, namely, test temperatures of -40°C and 40°C, and the measured absorption energies were compared.

[0037] Table 1 shows measurements of the volume percentage of martensitic structure, tensile strength, total elongation, and toughness. According to Table 1, the steels within the scope of the present invention had a better strength-ductility balance than the maraging steel and also had high toughness.

Example 2

[0038] The effect of structure was examined. All the test methods used were the same as those used in Example 1 except that the high-frequency heating was performed at varying temperatures to examine the effect of the volume percentage of martensite.

[0039] In comparative examples, for example, the amount of untransformed ferrite phase was increased by lowering the heating temperature. As a result, the volume percentage of martensite fell below 90%. The test results are shown in Table 2, which shows that the formation of less than 90% by volume of martensitic structure resulted in significantly decreased strength.

Example 3

[0040] The effects of other components were examined. Steels shown in Table 3 were produced by vacuum melting. The test methods used were the same as those used in Example 1. The test results are shown in Table 3, which shows that excessive contents of chromium and titanium resulted in decreased strength and excessive contents of nickel, vanadium, and niobium resulted in a saturated effect.

Example 4

[0041] The effect of the rate of temperature rise in heating for quenching was examined. A steel having the same composition as Steel No. 1-4 of Example 1 was subjected to furnace heating rather than high-frequency heating and was tempered under the same conditions as used in Example 1. This steel was examined for structure and properties. Table 4 shows a comparison of the rates of temperature rise, structures, and properties of the steel subjected to furnace heating (Steel No. 4-1) with the steel subjected to high-frequency heating (Steel No. 1-4 in Table 1).

[0042] According to Table 4, the use of furnace heating with a low rate of temperature rise for quenching resulted in formation of large martensite blocks. The steel could not achieve an elongation of 10% or more at a strength of 2,000 MPa or more and also had decreased toughness.

Example 5

[0043] The effect of tempering temperature was examined. Steels having the same composition as Steel No. 1-4 of

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Example 1 and steels having the same composition as Steel No. 1-12 of Example 1 were quenched under the same conditions as used in Example 1 and were tempered at varying temperatures, namely, 260°C, 380°C, and 450°C. The test results are shown in Table 5.

[0044] Table 5 shows that the tempering temperature exceeding 400°C resulted in a decreased concentration of boron at grain boundaries and significantly decreased toughness.

Example 6

[0045] Practical endless metal belts were evaluated for fatigue strength. The cold-rolled sheets of Example 1 with a thickness of 0.4 mm were cut to a width of 20 mm, were welded into an annular shape, and were quenched and tempered to prepare samples. These samples were suspended on SUJ2 pulleys shown in Fig. 1 and were rotated at 2,000 rpm under a predetermined tensile load ($P = 3,500$ N). The samples were evaluated for the number of revolutions before fracturing (the number of reciprocations of a particular point on the belts between the two pulleys). The materials used in the test were Steel Nos. 1-1 to 1-16 of Example 1 and Steel Nos. 5-1 to 5-6 of Example 5. The quenching and tempering conditions used for Steel Nos. 1-1 to 1-16 and Steel Nos. 5-1 to 5-6 were the same as those used in Examples 1 and 5, respectively. The test was performed three times for each material. The test results are shown in Table 6, which shows that the numbers of revolutions of the steels of the invention examples were nearly equivalent to that of the maraging steel. The steels of the comparative examples had decreased fatigue strength when used for practical components because of low tensile strength or ductility. The steels tempered at more than 400°C had decreased fatigue strength. Addition of more than 0.5% of molybdenum, namely, Steel No. 1-14, provided only a limited effect.

Table 1

Steel No.	Chemical composition (mass %)							Structure			Tensile strength (MPa)	Total elongation (%)	Charpy test (J)		Remarks
	C	Si	Mn	Al	Mo	B	Others	Volume % of M phase	Average block size (μm)	Dissolved B intensity ratio (boundary/interior; mass ppm)			Test temperature: -40°C	Test temperature: 40°C	
1-1	0.0025	0.002	0.006	0.084	4.87	0.0007	Ni: 17.99 Co: 10.44 Cr: 0.19 Ti: 0.48				2100	12.5	41.3	45.5	Con. Ex.
1-2	<u>0.20</u>	0.74	0.65	-	0.39	0.0019	-	93	<u>1.80</u>	19,2.5	<u>1750</u>	<u>16.5</u>	45.2	48.1	Com. Ex.
1-3	0.35	0.72	0.66	-	0.41	0.0020	-	94	1.48	15,2.0	2125	15.0	45.5	48.3	In. Ex.
1-4	0.43	0.71	0.65	-	0.40	0.0020	-	96	0.90	15,2.0	2230	12.5	42.7	45.3	In. Ex.
1-5	<u>0.55</u>	0.72	0.64	-	0.40	0.0021	-	96	0.85	12, <u>1.2</u>	2285	<u>8.5</u>	<u>11.0</u>	<u>18.2</u>	Com. Ex.
1-6	0.44	0.31	0.64	-	0.40	0.0019	-	96	0.90	14,2.0	2205	15.0	46.3	49.0	In. Ex.
1-7	0.43	0.95	0.65	-	0.39	0.0022	-	95	0.90	18,2.0	2190	12.0	43.6	45.5	In. Ex.
1-8	0.44	<u>1.12</u>	0.64	-	0.41	0.0020	-	96	0.80	18,2.0	2200	<u>8.0</u>	<u>9.2</u>	<u>14.1</u>	Com. Ex.
1-9	0.43	0.71	1.10	-	0.40	0.0020	-	95	0.90	18,2.0	2220	11.5	41.8	44.3	In. Ex.
1-10	0.43	0.72	<u>1.66</u>	-	0.41	0.0019	-	95	0.95	18,2.0	2235	<u>6.5</u>	<u>8.5</u>	<u>12.3</u>	Com. Ex.
1-11	0.42	0.71	0.65	-	<u>0.25</u>	0.0018	-	94	<u>1.60</u>	14,2.5	<u>1650</u>	<u>8.5</u>	<u>10.0</u>	<u>12.4</u>	Com. Ex.
1-12	0.44	0.75	0.66	-	0.31	0.0019	-	95	0.90	15,2.0	2080	12.0	43.5	46.6	In. Ex.
1-13	0.43	0.73	0.64	-	0.49	0.0020	-	94	0.80	10, 1.8	2265	14.5	47.2	48.6	In. Ex.
1-14	0.43	0.72	0.64	-	<u>0.60</u>	0.0020	-	95	0.80	8, <u>1.0</u>	2265	14.0	45.6	46.9	Com. Ex.
1-15	0.43	0.71	0.66	-	0.41	<u>0.0002</u>	-	90	<u>1.55</u>	<u>0,-</u>	<u>1900</u>	11.5	42.1	44.7	Com. Ex.
1-16	0.44	0.70	0.65	-	0.42	0.0060	-	96	0.90	45,3.0	2285	14.5	47.3	49.1	In. Ex.
* The underlined items are beyond the scope of the present invention.															

Steel No.	Chemical composition (mass %)							Structure	Tensile strength (Mpa)	Total elongation (%)	Charpy test (J)		Remarks
	C	Si	Mn	Al	Mo	B	Others	Volume % of M phase			Test temperature: -40°C	Test temperature: 40°C	
2-1	0.43	0.71	0.65	-	0.40	0.0020	-	96	2230	12.5	40.1	45.1	In. Ex.
2-2	0.43	0.71	0.65	-	0.40	0.0020	-	91	2040	15.0	44.6	47.2	In. Ex.
2-3	0.43	0.71	0.65	-	0.40	0.0020	-	<u>85</u>	<u>1840</u>	16.5	49.1	50.6	Com. Ex.
2-4	0.43	0.71	0.65	-	0.40	0.0020	-	<u>70</u>	<u>1650</u>	19.0	52.2	53.4	Com. Ex.
* The underlined items are beyond the scope of the present invention.													

Table 3

Steel No.	Chemical composition (mass %)												Structure	Tensile strength (MPa)	Total elongation (%)	Charpy test (J)	
	C	Si	Mn	Al	Mo	Cr	Ni	Cu	V	Ti	Nb	B	volume % of M phase			Test temperature : -40°C	Test temperature: 40°C
3-1	0.44	0.70	0.62	0.021	0.40	-	-	-	-	-	-	0.0021	94	2210	14.0	42.5	45.8
3-2	0.43	0.72	0.62	<u>0.031</u>	0.40	-	-	-	-	-	-	0.0018	94	2215	13.5	42.0	45.1
3-3	0.44	0.71	0.62	-	0.40	1.5	-	-	-	-	-	0.0020	94	2235	13.5	42.6	46.1
3-4	0.42	0.70	0.65	-	0.40	<u>3.0</u>	-	-	-	-	-	0.0018	95	<u>1765</u>	11.5	38.5	40.5
3-5	0.43	0.72	0.66	-	0.39	-	1.6	-	-	-	-	0.0021	95	2245	14.0	43.5	45.7
3-6	0.44	0.71	0.64	-	0.41	-	<u>2.5</u>	-	-	-	-	0.0018	95	2250	14.0	42.2	46.3
3-7	0.43	0.69	0.63	-	0.40	-	-	0.5	-	-	-	0.0020	94	2245	13.5	41.8	44.7
3-8	0.45	0.71	0.64	-	0.41	-	-	-	0.3	-	-	0.0018	94	2235	13.0	43.6	45.7
3-9	0.43	0.72	0.65	-	0.40	-	-	-	<u>0.6</u>	-	-	0.0021	95	2235	12.5	41.7	44.9
3-10	0.44	0.72	0.64	-	0.41	-	-	-	-	0.04	-	0.0020	95	2190	14.5	45.3	47.5
3-11	0.43	0.70	0.65	-	0.39	-	-	-	-	<u>0.11</u>	-	0.0019	94	<u>1650</u>	<u>9.0</u>	<u>11.3</u>	<u>15.5</u>
3-12	0.44	0.69	0.66	-	0.40	-	-	-	-	-	0.03	0.0020	94	2200	13.0	43.3	45.9
3-13	0.45	0.70	0.62	-	0.41	-	-	-	-	-	<u>0.11</u>	0.0022	96	2210	13.0	43.4	45.5
* The underlined items are beyond the scope of the present invention.																	

Table 4

Steel I No.	Chemical composition (mass %)						Rate of temperatur e rise in heating for quenching (°C/a)	Structure			Results		Charpy test (J)		Remarks 1	Remarks 2
	C	Si	Mn	Al	Mo	B	Others	Volume % of M phase	Average block size (μm)	Dissolved B intensity ratio (boundary/interior; mass ppm)	Tensile strength (MPa)	Total elongation (%)	Test temperature : -40°C	Test temperature : 40°C		
1-4	0.43	0.71	0.65	-	0.40	0.0020	-	96	0.90	15, 2.0	2230	12.5	42.7	45.3	In. Ex.	High- frequency quenching
4-1	0.43	0.71	0.65	-	0.40	0.0020	-	95	<u>2.50</u>	15, 2.0	<u>1710</u>	13.5	32.5	36.4	Com. Ex.	Furnace quenching

* The underlined items are beyond the scope of the present invention.

Table 5

Steel No.	Chemical composition (mass %)						Tempering temperature	Structure			Results		Charpy test (J)		Remarks
	C	Si	Mn	Al	Mo	B	Others	Volume % of M phase	Average block size (μm)	Dissolved B intensity ratio (boundary/interior; mass ppm)	Tensile strength (MPa)	Total elongation % (%)	Test temperature: -40°C	Test temperature: 40°C	
1-4	0.43	0.71	0.65	-	0.40	0.0020	-	96	0.90	15,2.0	2230	12.5	42.7	45.3	In. Ex.
5-1	0.43	0.71	0.65	-	0.40	0.0020	-	94	0.91	15, 1.9	2150	15.0	45.6	50.5	In. Ex.
5-2	0.43	0.71	0.65	-	0.40	0.0020	-	96	0.92	14, 1.6	2085	18.0	50.5	55.0	In. Ex.
5-3	0.43	0.71	0.65	-	0.40	0.0020	-	96	0.94	14, <u>1.1</u>	2050	20.0	<u>14.0</u>	<u>18.5</u>	Com. Ex.
1-12	0.44	0.75	0.66	-	0.31	0.0019	-	95	0.90	15,2.0	2080	12.0	43.5	46.6	In. Ex.
5-4	0.44	0.75	0.66	-	0.31	0.0019	-	94	0.91	15, 1.8	2050	13.5	44.2	47.3	In. Ex.
5-5	0.44	0.75	0.66	-	0.31	0.0019	-	95	0.93	15,1.5	2030	14.5	44.8	48.2	In. Ex.
5-6	0.44	0.75	0.66	-	0.31	0.0019	-	94	0.93	14, <u>1.2</u>	2005	16.0	<u>12.2</u>	<u>16.4</u>	Com. Ex.

* The underlined items are beyond the scope of the present invention.

Table 6

Steel No.	Chemical composition (mass %)							Tempering temperature	Number of revolutions before fracturing (x 10,000 revolutions)	Remarks
	C	Si	Mn	Al	Mo	B	Others			
1-1	0.0025	0.002	0.006	0.084	4.87	0.0007	Ni:17.99 Co: 10.44 Cr:0.19 Ti:0.48	-	780, 750, 725	Con. Ex.
1-2	<u>0.20</u>	0.74	0.65	-	0.39	0.0019	-	170°C	<u>110,105,120</u>	<u>Com. Ex.</u>
1-3	0.35	0.72	0.66	-	0.41	0.0020	-	170°C	720, 715, 720	In. Ex.
1-4	0.43	0.71	0.65	-	0.40	0.0020	-	170°C	750, 715, 760	In. Ex.
1-5	<u>0.55</u>	0.72	0.64	-	0.40	0.0021	-	170°C	<u>450.400.430</u>	Com. Ex.
1-6	0.44	0.31	0.64	-	0.40	0.0019	-	170°C	730, 725, 710	In. Ex.
1-7	0.43	0.95	0.65	-	0.39	0.0022	-	170°C	710, 720, 720	In. Ex.
1-8	0.44	<u>1.12</u>	0.64	-	0.41	0.0020	-	170°C	<u>500,510,490</u>	Com. Ex.
1-9	0.43	0.71	1.10	-	0.40	0.0020	-	170°C	745, 720, 715	In. Ex.
1-10	0.43	0.72	<u>1.66</u>	-	0.41	0.0018	-	170°C	<u>480,410,405,</u>	Com. Ex.
1-11	0.42	0.71	0.65	-	<u>0.25</u>	0.0018	-	170°C	<u>125,110,130</u>	Com. Ex.
1-12	0.44	0.75	0.66	-	0.31	0.0019	-	170°C	700, 715, 725	In. Ex.
1-13	0.43	0.73	0.64	-	0.49	0.0020	-	170°C	750, 740, 720	In. Ex.
1-14	0.43	0.72	0.64	-	<u>0.60</u>	0.0020	-	170°C	740, 725, 730	<u>Com. Ex.</u>
1-15	0.43	0.71	0.66	-	0.41	<u>0.0002</u>	-	170°C	<u>120, 165, 110</u>	<u>Com. Ex.</u>
1-16	0.44	0.70	0.65	-	0.42	0.0060	-	170°C	750, 735, 720	In. Ex.
5-1	0.43	0.71	0.65	-	0.40	0.0020	-	260°C	720, 735, 715	In. Ex.
5-2	0.43	0.71	0.65	-	0.40	0.0020	-	380°C	700, 705, 720	In. Ex.
5-3	0.43	0.71	0.65	-	0.40	0.0020	-	450°C	<u>425,440,450</u>	<u>Com. Ex.</u>
5-4	0.44	0.75	0.66	-	0.31	0.0019	-	260°C	690, 710, 720	In. Ex.
5-5	0.44	0.75	0.66	-	0.31	0.0019	-	380°C	685,690,715	In. Ex.

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(continued)

1-1	0.0025	0.002	0.006	0.084	4.87	0.0007	Ni:17.99 Co: 10.44 Cr:0.19 Ti:0.48	-	780, 750, 725	Con. Ex.
5-6	0.44	0.75	0.66	-	0.31	0.0019	-	450°C	<u>440,425,430</u>	<u>Com. Ex.</u>
* The underlined items are beyond the scope of the present invention.										

Industrial Applicability

[0046] A steel according to the present invention has a better balance between tensile strength and elongation and higher toughness than maraging steel and can therefore be used for components that to date have been conventionally produced with maraging steel.

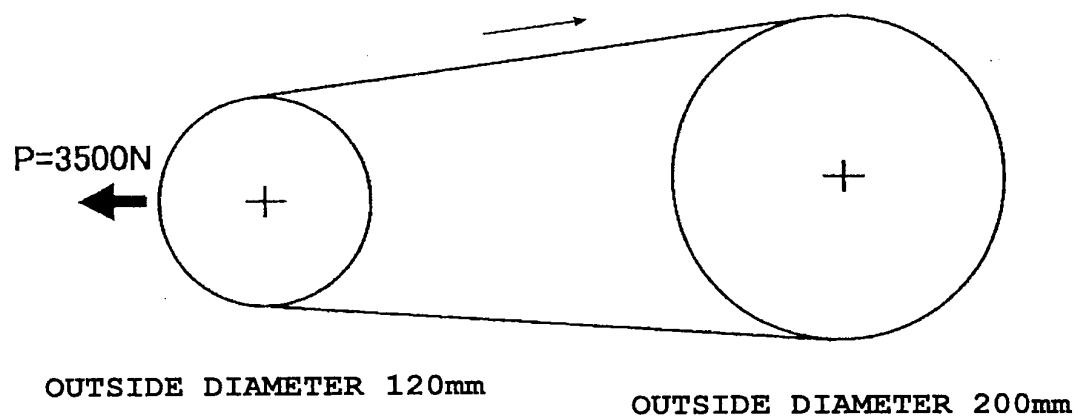
Claims

1. A steel for machine structural use with excellent strength, ductility, and toughness, the steel comprising, in percent by mass, more than 0.30% to 0.5% of carbon, 1.0% or less of silicon, 1.5% or less of manganese, 0.025% or less of aluminum, 0.3% to 0.5% of molybdenum, and 0.0005% to 0.01% of boron, the balance being iron and incidental impurities, the steel having a tensile strength of 2,000 MPa or more and a total elongation of 10% or more.
2. The steel for machine structural use with excellent strength, ductility, and toughness according to Claim 1, the steel further comprising, in percent by mass, at least one of 2.5% or less of chromium, 1.0% or less of copper, 2.0% or less of nickel, and 0.5% or less of vanadium.
3. The steel for machine structural use with excellent strength, ductility, and toughness according to Claim 1 or 2, the steel further comprising, in percent by mass, at least one of 0.1% or less of titanium and 0.1% or less of niobium.
4. A steel for machine structural use with excellent strength, ductility, and toughness, the steel comprising, in percent by mass, more than 0.30% to 0.5% of carbon, 1.0% or less of silicon, 1.5% or less of manganese, 0.025% or less of aluminum, 0.3% to 0.5% of molybdenum, and 0.0005% to 0.01% of boron, the balance being iron and incidental impurities, the steel having a structure comprising at least 90% by volume of martensitic structure, the martensitic structure comprising blocks having a size of 1.5 μm or less, wherein dissolved boron is contained in an amount of at least 0.0005% and is present at boundaries of prior austenite grains in a concentration at least 1.5 times that in the prior austenite grains.
5. The steel for machine structural use with excellent strength, ductility, and toughness according to Claim 4, the steel further comprising, in percent by mass, at least one of 2.5% or less of chromium, 1.0% or less of copper, 2.0% or less of nickel, and 0.5% or less of vanadium.
6. The steel for machine structural use with excellent strength, ductility, and toughness according to Claim 4 or 5, the steel further comprising, in percent by mass, at least one of 0.1% or less of titanium and 0.1% or less of niobium.
7. A steel sheet for machine structural use with excellent strength, ductility, and toughness, the steel sheet comprising the steel for machine structural use according to one of Claims 1 to 6 and having a thickness of 0.5 mm or less.
8. A metal belt comprising the steel sheet according to Claim 7, the metal belt having an annular shape.
9. A method for producing a steel for machine structural use with excellent strength, ductility, and toughness, the method comprising quenching a steel material by heating at a rate of temperature rise of 100°C/s or more and tempering the steel material at 100°C to 400°C, the steel material comprising, in percent by mass, more than 0.30% to 0.5% of carbon, 1.0% or less of silicon, 1.5% or less of manganese, 0.025% or less of aluminum, 0.3% to 0.5% of molybdenum, and 0.0005% to 0.01% of boron, the balance being iron and incidental impurities.
10. The method for producing a steel for machine structural use with excellent strength, ductility, and toughness according to Claim 9, wherein the steel material further comprises, in percent by mass, at least one of 2.5% or less of chromium, 1.0% or less of copper, 2.0% or less of nickel, and 0.5% or less of vanadium.
11. The method for producing a steel for machine structural use with excellent strength, ductility, and toughness according to Claim 9 or 10, wherein the steel material further comprises, in percent by mass, at least one of 0.1% or less of titanium and 0.1% or less of niobium.
12. A method for producing a steel sheet for machine structural use with excellent strength, ductility, and toughness, the method comprising quenching a steel sheet by heating at a rate of temperature rise of 100°C/s or more and tempering the steel sheet at 100°C to 400°C, the steel sheet comprising, in percent by mass, more than 0.30% to

0.5% of carbon, 1.0% or less of silicon, 1.5% or less of manganese, 0.025% or less of aluminum, 0.3% to 0.5% of molybdenum, and 0.0005% to 0.01% of boron, the balance being iron and incidental impurities, the steel sheet having a thickness of 0.5 mm or less.

- 5 **13.** The method for producing a steel sheet for machine structural use with excellent strength, ductility, and toughness according to Claim 12, wherein the steel sheet further comprises, in percent by mass, at least one of 2.5% or less of chromium, 1.0% or less of copper, 2.0% or less of nickel, and 0.5% or less of vanadium.
- 10 **14.** The method for producing a steel sheet for machine structural use with excellent strength, ductility, and toughness according to Claim 12 or 13, wherein the steel sheet further comprises, in percent by mass, at least one of 0.1% or less of titanium and 0.1% or less of niobium.
- 15 **15.** A method for producing a metal belt, the method comprising quenching a metal belt by heating at a rate of temperature rise of 100°C/s or more and tempering the metal belt at 100°C to 400°C, the metal belt comprising, in percent by mass, more than 0.30% to 0.5% of carbon, 1.0% or less of silicon, 1.5% or less of manganese, 0.025% or less of aluminum, 0.3% to 0.5% of molybdenum, and 0.0005% to 0.01% of boron, the balance being iron and incidental impurities, the metal belt having a thickness of 0.5 mm or less and having an annular shape.
- 20 **16.** The method for producing a metal belt according to Claim 15, wherein the metal belt further comprises, in percent by mass, at least one of 2.5% or less of chromium, 1.0% or less of copper, 2.0% or less of nickel, and 0.5% or less of vanadium.
- 25 **17.** The method for producing a metal belt according to Claim 15 or 16, wherein the metal belt further comprises, in percent by mass, at least one of 0.1% or less of titanium and 0.1% or less of niobium.

FIG. 1



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2006/313521

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/00(2006.01)i, C21D9/40(2006.01)i, C21D9/46(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, C21D9/40, C21D9/46

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 1996-2006

Kokai Jitsuyo Shinan Koho 1971-2006 Toroku Jitsuyo Shinan Koho 1994-2006

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.
X	JP 2005-126817 A (JFE Steel Corp.), 19 May, 2005 (19.05.05), Claims; Par. Nos. [0034], [0076], [0077] & WO 2005/031021 A1	1-17
A	JP 2003-105443 A (Honda Motor Co., Ltd.), 09 April, 2003 (09.04.03), Claims; Par. No. [0001] (Family: none)	1-17
A	JP 2005-68482 A (Daido Steel Co., Ltd.), 17 March, 2005 (17.03.05), Claims; Par. No. [0002] (Family: none)	1-17

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Date of the actual completion of the international search

31 July, 2006 (31.07.06)

Date of mailing of the international search report

08 August, 2006 (08.08.06)

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