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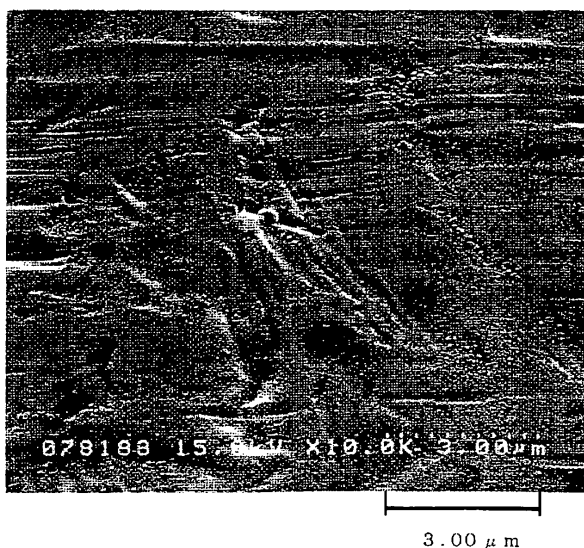
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(54) **MARAGING STEEL AND MARAGING STEEL FOR METALLIC BELT**

(57) A maraging steel for metallic belts which has a composition capable of being reduced in the content of TiN serving as a starting point for fatigue fracture in a high-cycle-rate region. The composition facilitates nitriding to heighten the surface hardness. The steel has a nitrided surface layer having increased compressive residual stress and hence improved flexural fatigue strength. In the steel, former austenite crystal

grains have been reduced in size in order to secure higher strength and higher ductility. The maraging steel consists of, by mass%, up to 0.01% C, up to 0.1% Si, up to 0.1% Mn, up to 0.01% P, up to 0.005% S, 17.0-22.0% Ni, 0.1-4.0% Cr, 3.0-7.0% Mo, from more than 7.0 to 20.0% Co, up to 0.1% Ti, up to 2.5% Al, up to 0.03% N, up to 0.005% O, up to 0.01% B (exclusive zero), and the balance of Fe and unavoidable impurities, wherein Co/3+Mo+4Al is 8.0-15.0%.

FIG.2



Description

TECHNICAL FIELD

5 **[0001]** The present invention relates to maraging steel having excellent fatigue strength, and maraging steel for a metallic belt used in continuously variable transmissions for automobiles.

BACKGROUND ART

10 **[0002]** Since maraging steel generally has a very high tensile strength of about 2000 MPa, it has been used for members requiring high strength, such as rocket parts, centrifugal separator parts, aircraft parts, continuously variable transmission parts of automobile engines, and dies in various applications. A typical maraging steel has a chemical composition of 18% Ni, 8% Co, 5% Mo, 0.4% Ti, 0.1% Al, and the balance of Fe.

15 The maraging steel contains appropriate amounts of Co, Mo and Ti as strengthening elements, and can obtain high strength by precipitating intermetallic compounds such as Ni_3Mo , Ni_3Ti , and Fe_2Mo by aging treatment. In particular, for a steel strip used for a component of continuously variable transmissions of automobile engines, the fatigue strength especially in a high cycle region is a needed important characteristic, so that it is required to make nonmetallic inclusions such as TiN, which are present in the maraging steel having high strength, fine as far as possible. Also, the maraging steel has been used as provided with improved fatigue strength by subjecting it to nitriding treatment to form a nitrided layer on the steel surface.

20 For a metallic belt used for continuously variable transmissions of automobile engines, an alloy improved to avoid the decrease in fatigue strength occurring with the nonmetallic inclusion being a starting point has been proposed (for example, see following Patent Documents 1 to 3).

25 Patent Document 1: JP-A-2004-514056
 Patent Document 2: JP-A-2001-240943
 Patent Document 3: JP-A-2002-167652

DISCLOSURE OF THE INVENTION

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PROBLEMS TO BE SOLVED BY THE INVENTION

35 **[0003]** In the alloy disclosed in JP-A-2004-514056, the content of Ti that forms nonmetallic inclusions is reduced to not more than 0.1%. Therefore, although this alloy is advantageous in making TiN, which serves as a start point of fatigue fracture, fine, the alloy has a problem of difficulty in nitriding treatment because it simply restrains the addition of an element forming nonmetallic inclusions.

The alloy disclosed in JP-A-2001-240943 is advantageous in making TiN, which serves as a start point of fatigue fracture, fine because it contains a reduced amount of Ti. In this alloy, however, it is difficult to ensure a high tensile strength because the content of Co, which is one of the strengthening elements, is kept low. Also, Si and Mn are added in order to ensure tensile strength, but the toughness may be decreased by the addition of Si and Mn.

40 The alloy disclosed in JP-A-2002-167652, also, is advantageous in making TiN, which serves as a start point of fatigue fracture, fine because it contains a reduced amount of Ti. In this alloy, however, since C is added positively to increase the strength, carbides of Cr, Mo and the like precipitates. Therefore, the fatigue strength may be decreased with the carbides serving as a starting point of fatigue fracture, or the weldability required for continuously variable transmission parts may be deteriorated by the positively added C.

45 Accordingly, an object of the present invention is to provide a maraging steel in which the chemical composition thereof can reduce TiN, which serves as a starting point of fatigue fracture in a high cycle region, the surface hardness is increased by facilitating nitriding treatment, the fatigue bending strength is improved by increasing the compression residual stress of a nitrided surface layer, and the former austenitic grains are made fine in order to ensure higher strength and ductility, and a maraging steel for a metallic belt using the aforementioned maraging steel.

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MEANS FOR SOLVING THE PROBLEMS

55 **[0004]** The present inventor found that the decrease in strength caused by the reduction in the Ti content can be compensated while keeping the contents of Ti and N low to reduce TiN, which is an inclusion detrimental for improving the fatigue strength, by increasing the contents of Co and Mo or adding Co and Mo as necessary and increasing the content of Al as well, and further by restricting the value of $\text{Co}/3 + \text{Mo} + 4\text{Al}$ to a proper range. Also, the present inventor found that in order to improve the tensile strength, ductility, and fatigue strength, it is effective to make the grains fine,

and this purpose can be attained by the addition of a trace amount of B.

Also, the present inventor found that in order to solve the difficulty of nitriding treatment caused by the reduction in Ti, the absolute value of the surface compression residual stress caused by nitriding can be increased by the addition of a proper amount of Cr or the addition of proper amounts of Cr and Al, and came at the present invention by keeping the carbon content at an impurity level to ensure the weldability.

[0005] Accordingly, there is provided the maraging steel consisting essentially of, by mass percent, not more than 0.01% C, not more than 0.1% Si, not more than 0.1% Mn, not more than 0.01% P, not more than 0.005% S, 17.0 to 22.0% Ni, 0.1 to 4.0% Cr, 3.0 to 7.0% Mo, more than 7.0% and not more than 20.0% Co, not more than 0.1% Ti, not more than 2.5% Al, not more than 0.03% N, not more than 0.005% O, and not more than 0.01% B (exclusive zero %), and the balance of Fe and unavoidable impurities, wherein the value of "Co/3 + Mo + 4Al" is 8.0 to 15.0% by mass percent. In the present invention, there are two types of preferable chemical compositions for achieving the above object. A first type preferable chemical composition has a positively added Al within the range of the above basic chemical composition. According to the first type preferable chemical composition, the maraging steel contains, by mass, 0.1 to 3.0% Cr, and more than 0.15 to not more than 2.5% Al. When positively adding Al, the maraging steel preferably comprises not more than 0.008% C, more than 18.0 to not more than 22.0% Ni, more than 5.0 to not more than 7.0%, and not more than 0.05% Ti, wherein the value of "Co/3 + Mo + 4Al" is 10.0 to 15.0% by mass percent.

More preferably, the maraging steel contains, by mass, from more than 12.0% to not more than 20.0% Co.

[0006] In contrast to the above chemical composition having positively added Al, a second type preferable chemical composition has a restricted amount of Al and a slightly much amount of Co within the range of the above basic chemical composition.

According to the first type preferable chemical composition, the maraging steel contains, by mass, from more than 10.0% to not more than 20.0% Co, not more than 0.05% Ti, and less than 0.1% Al, wherein the value of "Al+Ti" is less than 0.1%. In the present invention, in addition to the above basic chemical composition, the first type preferable chemical composition, and the second type preferable chemical composition, the maraging steel may contain, by mass, one or more of not more than 0.01% Ca and not more than 0.005% Mg.

It is also noted that the invention maraging steel has a fine grain size of ASTM No. 10 or more.

The present invention also relates to the above maraging steel for a metallic belt.

ADVANTAGES OF THE INVENTION

[0007] According to the invention maraging steel, it is possible to reduce TiN which may become a starting point of fatigue fracture, and to obtain high strength, surface high hardness after nitriding treatment, and high compression residual stress, so that when the maraging steel is used for a member required to have high fatigue strength, such as a power transmission metallic belt used for a continuously variable transmission of an automobile, industrially remarkable advantages, long durability for fatigue, for example, are obtainable.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008]

Fig. 1 is an electron microphotograph of the surface of an invention maraging steel, in which Al is positively added; and Fig. 2 is an electron microphotograph of the surface of an invention maraging steel containing a restricted amount of Al.

BEST MODE FOR CARRYING OUT THE INVENTION

[0009] The present invention has been made based on the above-described new knowledge. Herein below, functions of each element contained in the invention maraging steel is described.

Reasons why the chemical composition of the invention maraging steel is specified in the content ranges are set forth below. Unless otherwise specified, "%" means mass percent.

C (carbon) forms carbides together with Mo to reduce intermetallic compounds to be precipitated and to decrease the strength. Therefore, the carbon content must be kept low. Also, if carbon is added positively, the danger of deteriorating the weldability required for, for example, continuously variable transmission parts increases. For these reasons, the carbon content is set to be not more than 0.01%. Preferably the carbon content is not more than 0.008%.

Si is an element capable of making up for the decrease in strength caused by the reduction in Ti by making the intermetallic compounds precipitated during aging treatment or by forming intermetallic compounds together with Ni. However, since Si may decrease the toughness, in the present invention, the Si content must be kept low to ensure toughness and ductility. The addition of Si exceeding 0.1% decreases the toughness and ductility, so that the Si content is set to be not more than 0.1%. The preferable range for surely ensuring toughness and ductility is not more than 0.05%.

[0010] Mn is an element capable of making up for the decrease in strength caused by the reduction in Ti because it forms intermetallic compounds together with Ni during aging treatment and contributes to age hardening. However, since Mn may decrease the toughness, in the present invention, the Mn content must be kept low. The addition of Mn exceeding 0.1% decreases the toughness and ductility, so that the Mn content is set to be not more than 0.1%. The preferable range for surely ensuring toughness and ductility is not more than 0.05%.

P (phosphorous) and S (sulfur) are detrimental elements that make the maraging steel brittle and decrease the fatigue strength by segregating at the old austenitic grain boundaries or by forming inclusions. Therefore, the P content is set to be not more than 0.01%, and the S content is set to be not more than 0.005%. The preferable ranges are not more than 0.005% for P and not more than 0.004% for S.

[0011] Cr is an element that has strong affinity with nitrogen in nitriding, decreases the nitriding depth, increases the nitriding hardness, and increases the compression residual stress of the nitrided surface. Therefore, the addition of Cr is essential. However, the content less than 0.1% does not achieve the effects. On the other hand, even if Cr is added exceeding 4.0%, the effects are not improved further, and the strength after aging decreases greatly. Therefore, the Cr content is set to be 0.1 to 4.0%. When Al is added positively, the sufficient upper limit of Cr content is 3.0%.

Ni stably forms a low-C martensitic structure, which is the matrix structure of maraging steel. Therefore, at least 17.0% of Ni must be added. However, if the Ni content exceeds 22.0%, the austenitic structure is made stable, and the martensite transformation becomes difficult to take place. Therefore, the Ni content is set to be 17.0 to 22.0%. The preferable Ni range is more than 18.0% and not more than 22.0%.

Mo is an important element that forms fine intermetallic compounds such as Ni_3Mo and Fe_2Mo during aging treatment and contributes to precipitation strengthening. Also, Mo is an effective element for increasing the surface hardness and compression residual stress caused by nitriding. If the Mo content is less than 3.0%, the tensile strength is insufficient, and on the other hand, if it is more than 7.0%, coarse intermetallic compounds, in which Fe and Mo are the principal elements, become liable to be formed. Therefore, the Mo content is set to be 3.0 to 7.0%. The preferable Mo range is more than 5.0% and not more than 7.0%.

[0012] Co is an element that increases the degree of solid solution of the aging precipitate forming elements such as Mo and Al at the solid solution heat treatment temperature without exerting a great influence on the stability of the martensitic structure of matrix, promotes precipitation of fine intermetallic compounds containing Mo and Al by decreasing the degree of solid solution of Mo and Al in the aging precipitation temperature region, and contributes to aging precipitation strengthening. Therefore, much Co must be added from the viewpoint of strength and toughness. If the Co content is not more than 7.0%, the maraging steel in which Si, Mn and Ti are reduced has difficulty in obtaining sufficient strength. On the other hand, if the Co content exceeds 20.0%, austenite is made stable and it is difficult to obtain martensitic structure. Therefore, the Co content is set to be more than 7.0% and not more than 20.0%. The preferable Co range is more than 12.0% and not more than 20.0%.

Also, when the addition of Al is restricted, since Al contributing to strengthening is restricted, the Co content should be made slightly high.

Therefore, the preferable Co range is made more than 10.0% and not more than 20.0%.

[0013] Ti is inherently one of the important strengthening elements in the maraging steel, but at the same time, is a detrimental element that forms TiN or Ti(C,N) , which is an inclusion, and thereby decreases the fatigue strength especially in the super-high cycle region. Therefore, when importance is attached to fatigue strength, the Ti content must be kept low as an impurity.

Also, Ti easily forms a thin and stable oxide film on the surface, and the formation of this oxide film hinders nitriding reaction, so that it is difficult to obtain a sufficient compression residual stress on the nitrided surface. To perform nitriding easily or to increase the compression residual stress on the nitrided surface, the content of Ti, which is a detrimental impurity element, must be kept low.

If the Ti content is more than 0.1%, a sufficient effect of reducing TiN or Ti(C,N) cannot be achieved, and a stable oxide film is easily formed on the surface. Therefore, the Ti content is set to be not more than 0.1%. Preferably, the Ti content should be not more than 0.05%, and further preferably not more than 0.01%.

[0014] In the present invention, Al is added positively, or the addition of Al is restricted.

When Al is added positively, the strength of maraging steel can be improved. Therefore, when importance is attached to strength, Al should be added positively. The Al content in the case of positive addition is described below.

Al is an element that is usually added in small amounts for deoxidation, and forms intermetallic compounds together with Ni during aging treatment to contribute to strengthening. For the maraging steel for a metallic belt in accordance with the present invention, in which Si, Mn and Ti are reduced, it is preferred that the strength be increased by the addition of Al. Also, to facilitate the nitriding treatment in the maraging steel in which Ti is reduced to obtain a good nitrided layer, as well, Al must be added. If the Al content is not more than 0.15%, sufficient strengthening action due to aging treatment cannot be accomplished. On the other hand, if the Al content is more than 2.5%, much AlN and Al_2O_3 inclusions are formed to decrease the fatigue strength, or a thin and stable oxide film is formed on the surface to hinder nitriding reaction. Therefore, the Al content is set to be more than 0.15% and not more than 2.5%. When Al is added

positively, the surface roughness of maraging steel is somewhat reduced in some cases. Therefore, the preferable upper limit at the time when Al is added positively is made 1.5%.

[0015] When the Al content is restricted, the nonmetallic inclusions in the maraging steel can be reduced. Also, to easily keep smooth the surface roughness of the maraging steel on account of Al, the starting point of fatigue fracture is reduced, and when importance is attached to fatigue strength, Al should be restricted. The preferable Al content in the case where Al is restricted is described below.

Al forms nonmetallic inclusions by combining with oxygen and nitrogen, and may decrease the fatigue strength, so that when importance is attached to fatigue strength, the Al content should be kept low.

If the Al content is 0.1% or more, AlN and Al₂O₃ inclusions are formed easily, and thereby the fatigue strength may be decreased. Therefore, the Al content should be restricted to less than 0.1%. The preferable Al range is not more than 0.05%.

Also, since both of Al and Ti are elements that form nonmetallic inclusions, keeping the total amount of Al and Ti low is effective in improving the fatigue strength, so that the content of "Al+Ti" is made not more than 0.1%. The preferable range of "Al+Ti" is not more than 0.07%.

[0016] All of Co, Mo and Ti are main strengthening elements in the maraging steel, and Al also is an element contributing to aging strengthening of the maraging steel. If the Ti content is kept low, when the contents of Co and Mo are increased or Al is added positively, it is necessary to make up for the decrease in strength on account of Ti by increasing the content of Al in addition to Co and Mo. However, the contributions of the elements to the strengthening are not the same, and the magnitudes of strengthening due to Co and Al are 1/3 times and four times the magnitude of strengthening due to Mo, respectively.

Therefore, the strengthening due to Co, Mn and Al can be expressed by $Co/3 + Mo + 4Al$. If the value of $Co/3 + Mo + 4Al$ is less than 8.0% by mass percent, the strength is insufficient. On the other hand, if the value thereof exceeds 15.0%, the strength becomes too high, and the toughness may be decreased. Therefore, the value of $Co/3 + Mo + 4Al$ is set to be 8.0 to 15.0%. The preferable range of $Co/3 + Mo + 4Al$ is 10.0 to 15.0%.

[0017] N (nitrogen) is an impurity element that forms an inclusion of TiN or Ti(C,N) by combining with Ti to decrease the fatigue strength especially in a super-high cycle region. In the maraging steel containing Ti, to prevent the formation of coarse TiN or Ti(C,N), the N content must be kept significantly low. However, in the maraging steel scarcely containing Ti, even the amount of N mixed in on account of usual vacuum melting exerts a little adverse influence, so that the N content is set to be not more than 0.03%. Desirably, the N content should be not more than 0.01%. Further desirably, the N content should be not more than 0.005%.

O (oxygen) is an impurity element that forms oxide-based inclusions to decrease the toughness and fatigue strength. Therefore, the O content was restricted to not more than 0.005%. Desirably, the O content should be not more than 0.003%.

B (boron) is an element that makes fine the old austenitic grains at the time when solid solution heat treatment is performed after cold working to contribute to the strengthening, and has an effect of restraining surface roughness, therefore being added indispensably. If the B content is more than 0.01%, the toughness decreases, so that the B content is set to be not more than 0.01% (excluding 0%). Desirably, the B content should be not more than 0.005% (excluding 0%). The preferable lower limit of the content of B capable of surely making the old austenitic grains fine is 0.0002%, and the further preferable lower limit thereof is 0.0003%.

[0018] The present invention steel may contain not more than 0.01% Ca and/or not more than 0.005% Mg.

In the present invention steel, the ingot thereof can be manufactured by vacuum induction melting or melting in a vacuum atmosphere, for example, by further performing vacuum arc remelting or electroslag remelting after the vacuum induction melting. However, even if melting in a vacuum atmosphere is performed, it is technically difficult to completely eliminate nonmetallic inclusions.

In the present invention steel, Al is added positively in order to improve the strength in some cases. Therefore, there is a concern about occurrence of coarse and hard Al₂O₃ inclusions having a size exceeding, for example, 25 μm, or a concern about occurrence of cluster Al₂O₃. The Al₂O₃ inclusions have high hardness and high melting point, and are scarcely deformed, for example, even during hot plastic working. Therefore, there is a possibility of producing a surface defect on the maraging steel for a metallic belt due to the occurrence of a flaw on a roll, for example, during cold rolling.

For this reason, the Al₂O₃ inclusions should be made composite inclusions combined with other oxides to decrease the hardness or to lower the melting point. Also, preferably, an element capable of preventing occurrence of cluster Al₂O₃ is added in order to prevent inclusion defects.

[0019] As an element effective in making Al₂O₃ inclusions composite inclusions, Si, Mn, Ca and Mg can be raised. In the present invention, the amounts of addition of Si and Mn are restricted as elements that reduce the toughness and ductility. Therefore, preferably by adding one or more of Ca and Mg other than Si and Mn, Al₂O₃ inclusions are made to be composite inclusions. Also, Ca and Mg have an effect of preventing occurrence of cluster Al₂O₃. Therefore, in the present invention steel, not more than 0.01% Ca and/or not more than 0.005% Mg are added.

To surely achieve the effects of Ca and Mg, the lower limit of content should be 0.001% for Ca and 0.0001% for Mg.

The elements other than explained above are made Fe and unavoidable impurities.

The following element may be added for the purpose of deoxidation, desulfurization, and the like in the following range:

$$Zr \leq 0.01\%$$

[0020] In the maraging steel of the present invention, the old austenitic grains (herein, in the case of maraging steel, grains mean the old austenitic grains) can be so fine as correspond to ASTM No. 10 or more by solid solution heat treatment performed at a proper temperature corresponding to the composition, for example, at a temperature of about 780 to 1000°C after cold working of not less than 10%.

In the maraging steel of the present invention, it is expectable to obtain effects that the hardness, tensile strength, fatigue strength, impact toughness, and the like can be increased by making the grains fine, and that in the case of a steel strip, the surface roughness can be reduced.

[0021] In the invention maraging steel, not more than 2.5% of Al is contained as mentioned above.

Concerning the maraging steel of the present invention, there was obtained a new knowledge that a characteristic phenomenon that the surface shape of maraging steel becomes rough according to the Al content occurs. It is presumed that the cause for this phenomenon is that Al having a high diffusion coefficient concentrates on the surface due to high-temperature heat treatment such as solid solution heat treatment and the atmosphere thereof, whereby surface oxidation is brought about.

If a surface state becomes rough, for example, in the case where the maraging steel of the present invention is used for a power transmission metallic belt used for a continuously variable transmission of an automobile, the risk of fatigue fracture in the low cycle side becomes great. Therefore, the surface shape should be kept smooth as far as possible by Al. In particular, in the maraging steel in which Al is added positively, to make the surface of maraging steel smooth, a method for making the surface smooth by mechanical grinding or chemical surface etching is used. However, it is important that the surface concentration of Al be restrained as far as possible in the state of the raw material of maraging steel.

For the raw material before cold working, it is thought that the oxidized layer formed on the raw material surface is removed, whereby the Al concentrated layer on the surface is also removed. Therefore, the atmosphere of solid solution heat treatment performed especially during cold working should be adjusted to the atmosphere of oxygen or nitrogen that is difficult to form oxides or nitrides by combining with Al. For example, a vacuum atmosphere, hydrogen atmosphere, or argon atmosphere should be used. Among these, the hydrogen atmosphere and the argon atmosphere, which are capable of continuously treating cold rolled materials, are favorable from the viewpoint of productivity. In particular, hydrogen is preferably used because of being inexpensive.

[0022] The invention maraging steel scarcely contain Ti that forms a stable oxide film having a possibility of hindering nitriding. Therefore, various types of nitriding treatment such as usual gas nitriding, gas nitrocarburizing, nitrosulfurizing, ion nitriding, and salt bath nitriding can be performed easily. Also, for the invention maraging steel for a metallic belt, which contains no Ti, regarding the absolute value of compression residual stress of the nitrided layer liable to decrease, as well, the absolute value of compression residual stress of the nitrided layer can be increased by Cr and Al that have an effect of enhancing the nitriding hardness and the absolute value of compression residual stress of the nitrided layer. Also, the maraging steel in which the chemical composition thereof is adjusted to the above-described range specified in the present invention is formed into a strip shape having a thickness of, for example, 0.05 mm or smaller to be used for a steel strip of maraging steel for a metallic belt, and nitriding treatment is performed under the conditions suitable for the steel strip of maraging steel for a metallic belt. By doing this, a thin nitrided layer having a thickness of about 20 to 40 μm can be formed on the surface with nitrides being scarcely formed, and a high compression residual stress can be given to the surface, so that the improvement in fatigue characteristics can be expected.

A higher compression residual stress of the surface is thought to be advantageous in fatigue characteristics, and the control of the compression residual stress can be carried out by appropriately adjusting the thickness of the nitrided layer. The maraging steel for a metallic belt of the present invention has a high tensile strength and high fatigue strength, and can be nitrided easily, so that this maraging steel is suitable for a metallic belt for a continuously variable transmission of an automobile engine.

EXAMPLES

[0023] The present invention will be explained in more detail with reference to the following Example.

The invention maraging steel and a comparative steel were melted in a vacuum induction melting furnace to produce ingots of 10 kg, and the ingots were subjected to homogenizing, and then were hot forged. Further, steel strips each having a thickness of about 0.3 mm were produced by hot rolling and cold rolling, whereby maraging steels for a metallic

belt were produced. Thereafter, solid solution heat treatment was performed at 820 to 900°C, and further aging treatment was performed at 490°C. Subsequently, gas nitrocarburizing was performed under the condition that the nitride depth is 20 to 40 μm at 450 to 470°C.

The solid solution heat treatment was performed in a hydrogen atmosphere. Figs. 1 and 2 are electron microphotographs of the surface of steel strips each having a thickness of 0.3 mm of the invention steel Nos. 6 and 15, respectively. Fig. 1 shows a maraging steel in which Al is added positively. For this maraging steel, although the surface was somewhat rough, a surface defect that serves as a starting point of fracture could not be confirmed.

Fig. 2 shows a maraging steel in which the addition of Al is restricted. For this maraging steel, it is found that the surface shape is smooth.

[0024] Table 1 shows the chemical compositions of invention maraging steel Nos. 1 to 8 (with positively added Al), the invention maraging steel Nos. 11 to 16 (with restricted amounts of Al), and conventional steel and comparative steel Nos. 21 and 22, respectively. Comparative steel No. 21 is a conventional steel containing Ti, and comparative steel No. 22 is a maraging steel in which Ti is not contained, and Al is not added. In any of the maraging steels, the carbon content was adjusted to the range of not more than 0.01% to prevent the deterioration in weldability. Also, in invention steel Nos. 5 and 6 in which Al was added positively, Mg was added. The Mg content was 10 ppm for No. 5 and 6 ppm for No. 6. Also, in invention steel Nos. 15 and 16 in which the Al content was restricted, as well, Mg was added. The Mg content was 7 ppm for No. 15 and 12 ppm for No. 16.

Although not shown in the table, fine inclusions were observed and analyzed in 10 view areas at random at x1000 magnification by using an electron microscope and an X-ray analyzer. Consequently, on all specimens excluding comparative steel No. 21, inclusions of TiN and Ti(C,N) exceeding 3 μm were not observed.

Also, on invention steel Nos. 1, 6 and 15 on which fatigue test described later was conducted, observation of cross section was accomplished in 10 view areas at x1000 magnification by using an electron microscope, and consequently, Al_2O_3 inclusions could not be observed.

[0025] Table 2 shows old austenitic grain size numbers and tensile strength after aging of specimen, internal hardness and surface hardness after nitriding treatment, and surface residual stress after gas nitrocarburizing. In Table 2, the symbol "+" of residual stress represents tension, and the symbol "-" thereof represents compression. All of the residual stresses are compression residual stresses. Table 3 shows the results of fatigue tests after aging at 480°C conducted on the invention steel Nos. 1, 6 and 15, conventional steel No. 21, and comparative steel No. 22.

For the fatigue test, various stress applying modes such as rotational bending, tension/compression, and torsion can be used. Since the invention maraging steel is used as a strip material, an evaluation method in which bending stress is applied is suitable. Therefore, it is apparent that, in the repeat bending fatigue test, unless fracture occurs when a high stress such as to fracture the conventional maraging steel is applied, the maraging steel has a high fatigue strength. Therefore, the repeat bending fatigue test was conducted until the number of cycles of fracture reaches 10^7 cycles when a repeat bending stress with an average stress of 537 MPa and a maximum stress of 1016 MPa is applied.

[0026]

Table 1

Steel No.	C	Si	Mn	P	S	Cr	Ni	Mo	Co	Ti	Al
1	0.006	0.01	0.02	0.003	0.001	1.1	18.7	5.5	16.1	0.005	0.22
2	0.007	0.02	0.03	0.004	0.002	1.6	18.6	5.4	16.3	0.007	0.26
3	0.004	0.02	0.01	0.003	0.001	0.9	18.8	5.6	12.9	0.009	1.10
4	0.005	0.01	0.03	0.004	0.002	1.2	18.5	5.3	14.2	0.011	0.86
5	0.003	0.01	0.01	0.003	0.001	0.1	18.9	4.9	12.6	0.010	0.87
6	0.003	0.01	0.01	0.003	0.001	0.1	18.7	6.4	9.2	0.006	1.01
7	0.003	0.01	0.01	0.002	0.001	0.6	18.9	5.5	12.7	0.007	0.52
8	0.004	0.02	0.01	0.003	0.002	0.4	18.7	6.4	9.3	0.009	0.59
11	0.004	0.02	0.01	0.002	0.002	1.6	18.6	5.4	16.2	0.011	0.03
12	0.006	0.01	0.03	0.003	0.001	1.3	18.5	5.6	17.8	0.013	0.02
13	0.005	0.03	0.02	0.002	0.002	2.6	18.9	5.7	16.6	0.009	0.05
14	0.003	0.02	0.02	0.003	0.001	2.2	18.7	5.2	15.9	0.012	0.04
15	0.003	0.01	0.01	0.003	0.001	1.0	19.3	5.1	12.8	0.007	0.03
16	0.004	0.01	0.02	0.002	0.001	1.1	18.9	5.9	10.4	0.010	0.03
21	0.004	0.02	0.02	0.002	0.001	-	18.7	4.9	9.2	0.470	0.09
22	0.006	0.03	0.02	0.004	0.002	-	17.9	5.1	15.8	0.008	0.03

Continued ...

Table 1 (Cont'd)

N	O	B	Balance	Co/3+Mo+4Al	Al+Ti	Remarks
0.0008	0.0010	0.0012	Fe and unavoidable impurities	11.7	0.225	Invention Steel
0.0010	0.0012	0.0014	Fe and unavoidable impurities	11.9	0.267	Invention Steel
0.0007	0.0009	0.0018	Fe and unavoidable impurities	14.3	1.109	Invention Steel
0.0013	0.0015	0.0011	Fe and unavoidable impurities	13.5	0.871	Invention Steel
0.0005	0.0009	0.0011	Fe and unavoidable impurities	12.6	0.880	Invention Steel
0.0006	0.0008	0.0007	Fe and unavoidable impurities	13.5	1.016	Invention Steel
0.0009	0.0006	0.0006	Fe and unavoidable impurities	11.8	0.527	Invention Steel
0.0011	0.0009	0.0008	Fe and unavoidable impurities	11.9	0.599	Invention Steel
0.0009	0.0011	0.0013	Fe and unavoidable impurities	10.9	0.041	Invention Steel
0.0012	0.0008	0.0011	Fe and unavoidable impurities	11.6	0.033	Invention Steel
0.0008	0.0006	0.0010	Fe and unavoidable impurities	11.4	0.059	Invention Steel
0.0011	0.0012	0.0014	Fe and unavoidable impurities	10.7	0.052	Invention Steel
0.0006	0.0018	0.0015	Fe and unavoidable impurities	9.5	0.037	Invention Steel
0.0005	0.0009	0.0012	Fe and unavoidable impurities	9.5	0.040	Invention Steel
0.0008	0.0007	-	Fe and unavoidable impurities	8.3	0.479	Conventional Steel
0.0012	0.0011	-	Fe and unavoidable impurities	10.5	0.038	Comparative Steel

* Note: "-" means "no addition".

[0027]

Table 2

Steel No.	After aging		After gas soft-nitriding treatment			Remarks
	G.S. No.	Tensile strength (MPa)	Internal hardness (HV)	Surface hardness (HV)	Surface residual stress (MPa)	
1	11.0	2083	689	873	-1268	Invention Steel
2	11.0	2089	693	882	-1387	Invention Steel
3	11.5	2153	721	957	-1273	Invention Steel
4	11.5	2126	704	931	-1324	Invention Steel
5	10.5	1983	607	937	-1211	Invention Steel
6	11.0	2041	618	944	-1163	Invention Steel
7	11.0	1962	654	881	-1357	Invention Steel
8	10.5	1911	637	893	-1220	Invention Steel
11	10.5	2012	671	846	-1323	Invention Steel
12	11.0	2094	706	859	-1216	Invention Steel
13	11.0	2073	687	862	-1367	Invention Steel
14	10.5	1968	653	847	-1264	Invention Steel
15	10.5	1736	579	811	-1452	Invention Steel
16	10.5	1703	568	821	-1449	Invention Steel
21	9.5	1776	593	824	-1029	Conventional Steel
22	9.5	1964	653	793	-991	Comparative Steel
* Note: The surface residual stress is of compression residual stress.						

[0028]

Table 3

Steel No.	Number of cycles for fracture	Remarks
1	10 ⁷ (not fractured)	Invention Steel
6	10 ⁷ (not fractured)	Invention Steel
15	364900	Invention Steel
21	340500	Conventional Steel
* Note: Fatigue test was conducted with maximum stress of 1016 MPa and average stress of 537 MPa.		

[0029] Table 2 indicates that all of the maraging steels for a metallic belt using the maraging steels of the present invention have a tensile strength after aging of 1700 MPa or higher, having a sufficient strength of a metallic belt. In particular, the maraging steels in which Al was added positively had a tensile strength after aging of 1900 MPa or higher. Also, it can be seen that even after nitriding, the maraging steels have high internal hardness, surface hardness, and surface compression residual stress, and that they have characteristics equivalent to or higher than those of conventional steel No. 21 containing Ti.

Also, invention steels has the austenitic grain size so fine as correspond to ASTM No. 10 or more due to the effect of adding B.

On the other hand, comparative steel No. 22

in which Ti is not added and also Cr and Al are not added has a low tensile strength after aging and low internal hardness, surface hardness, and surface compression residual stress after nitriding as compared with present invention steels. Also, the comparative steel had slightly coarse grains because it did not contain B.

Further, Table 3 indicates that for present invention steels No. 1 and No. 6, the number of cycles for fracture exceeds 10^7 cycles in the fatigue test result after aging. Also, it can be seen that present invention steel No. 15 also has fatigue characteristics higher than those of conventional steel No. 21. Also, since present invention steel has nitriding characteristics higher than those of conventional steel as described above, further improvement in fatigue characteristics can be expected by nitriding treatment.

Thus, the maraging steel for a metallic belt using the maraging steel of the present invention can be provided with a fatigue strength higher than that of the conventional maraging steel.

INDUSTRIAL APPLICABILITY

[0030] The maraging steel in accordance with the present invention can be used for a metallic belt used under stringent conditions, and therefore can be used for members requiring high tensile strength and high fatigue strength, such as a power transmission metallic belt used for an automotive continuously variable transmission and the like.

Claims

1. Maraging steel consisting essentially of, by mass percent, not more than 0.01% C, not more than 0.1% Si, not more than 0.1% Mn, not more than 0.01% P, not more than 0.005% S, 17.0 to 22.0% Ni, 0.1 to 4.0% Cr, 3.0 to 7.0% Mo, more than 7.0% and not more than 20.0% Co, not more than 0.1% Ti, not more than 2.5% Al, not more than 0.03% N, not more than 0.005% O, and not more than 0.01% B (exclusive zero %), and the balance of Fe and unavoidable impurities, wherein the value of "Co/3 + Mo + 4Al" is 8.0 to 15.0% by mass percent.
2. The maraging steel according to claim 1, wherein the Cr content is 0.1 to 3.0% by mass, and the Al content is more than 0.15% and not more than 2.5% by mass.
3. The maraging steel according to claim 1 or 2, wherein the carbon content is not more than 0.008% by mass, the Ni content is more than 18.0% and not more than 22.0% by mass, the Mo content is more than 5.0% and not more than 7.0% by mass, and the Ti content is not more than 0.05% by mass, wherein Co/3 + Mo + 4Al is 10.0 to 15.0% by mass percent.
4. The maraging steel according to any one of claims 1 to 3, wherein the Co content is more than 12.0% and not more than 20.0% by mass.
5. The maraging steel having high fatigue strength according to claim 1, wherein the Co content is more than 10.0% and not more than 20.0% by mass, the Ti content is not more than 0.05% by mass, and less than 0.1% Al by mass, wherein the value of "Al+Ti" is less than 0.1% by mass.
6. The maraging steel according to any one of claims 1 to 5, which contains, by mass percent, one or more of not more than 0.01% Ca and not more than 0.005% Mg.
7. The maraging steel according to any one of claims 1 to 6, which has a fine grain size of ASTM No. 10 or more.
8. A maraging steel for a metallic belt, which is made of the maraging steel as defined in any one of claims 1 to 7.

FIG.1

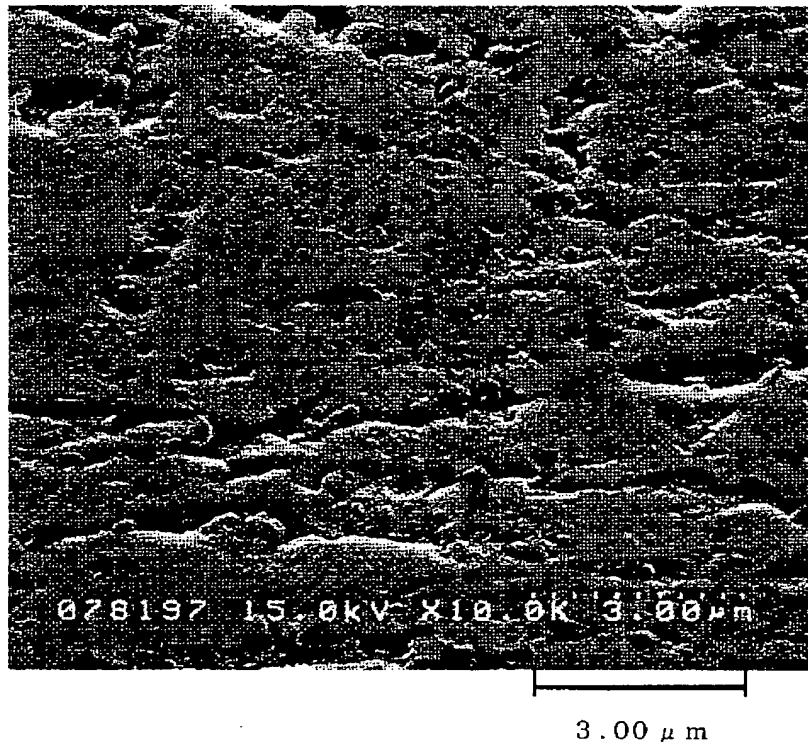
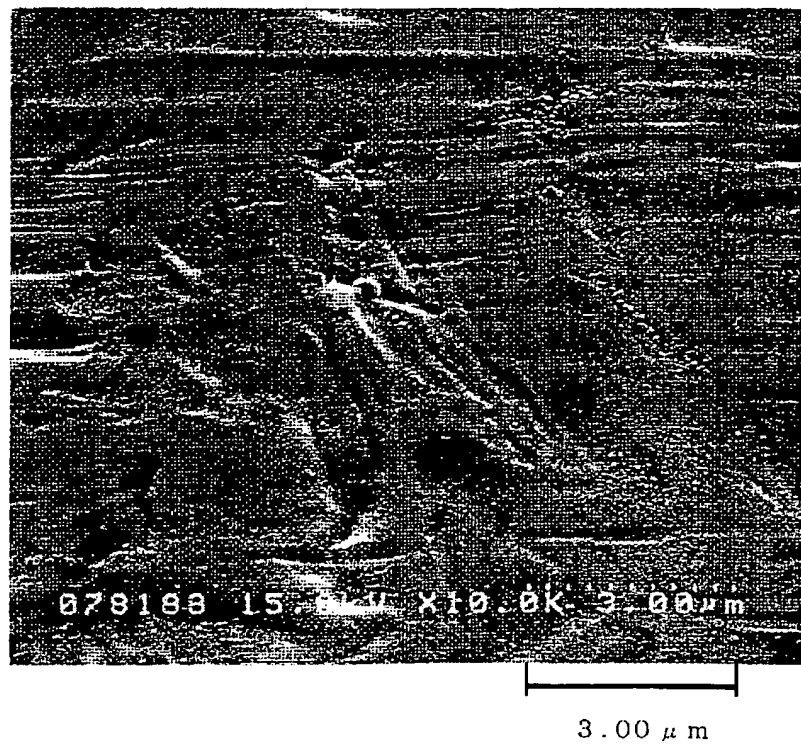


FIG.2



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2007/063832

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/00(2006.01) i, C22C38/54(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)

C22C38/00-38/60

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	1996-2007
Kokai Jitsuyo Shinan Koho	1971-2007	Toroku Jitsuyo Shinan Koho	1994-2007

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

WPI (DIALOG)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
E, X	JP 2007-186780 A (Hitachi Metals, Ltd.), 26 July, 2007 (26.07.07), Full text (Family: none)	1-8
A	JP 10-152759 A (Daido Steel Co., Ltd.), 09 June, 1998 (09.06.98), Claims (Family: none)	1-8
A	JP 2002-161308 A (Daido Steel Co., Ltd.), 04 June, 2002 (04.06.02), Claims (Family: none)	1-8

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

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"&" document member of the same patent family

Date of the actual completion of the international search
02 October, 2007 (02.10.07)Date of mailing of the international search report
09 October, 2007 (09.10.07)Name and mailing address of the ISA/
Japanese Patent Office

Authorized officer

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2007/063832

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2002-285290 A (Daido Steel Co., Ltd.), 03 October, 2002 (03.10.02), Claims (Family: none)	1-8

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REFERENCES CITED IN THE DESCRIPTION

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- JP 2001240943 A [0002] [0003]
- JP 2002167652 A [0002] [0003]