HIGH-STRENGTH LOW-ALLOY TITANIUM ALLOY AND PRODUCTION METHOD FOR SAME

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ABSTRACT

To provide a titanium alloy which is a high-strength low-alloy with a 750 MPa or more in terms of tensile strength. A production method is capable of producing the titanium alloy by using a low-priced, low-grade sponge titanium as a raw material. This high-strength low-alloy titanium alloy has an alloy composition containing O of from 0.2 to 0.8%, C of from 0.01 to 0.15%, N of from 0.01 to 0.07%, Fe of from 0.3 to 1.0% and the balance being substantially Ti. At the time of production, a low-grade sponge Ti containing N of 0.01% or more and Fe of 0.2% or more is used in at least a portion of raw materials to allow it to be a source of the aforementioned Ni and Fe components.
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CROSS-REFERENCE TO RELATED APPLICATIONS


BACKGROUND OF THE INVENTION

[0002] 1. Field of the Application

[0003] The present invention relates to a high-strength low-alloy titanium alloy for use in forming various types of structural materials that require high strength, and a production method thereof.

[0004] 2. Description of Background Art

[0005] Spectacle frames, golf club heads and automotive engine members such as a valve retainer are required to be not only light in weight but also high in strength. Since pure titanium is excellent in corrosion resistance, it has been used in applications mostly in the chemical industry which require corrosion resistance. Strength thereof can be enhanced by appropriately controlling an amount of O or Fe contained in Ti. With regard to such high-strength titanium, the specifications of from a first type to a fourth type are defined by JIS in accordance with the levels of tensile strength.

[0006] Recently, a high-strength low-alloy titanium alloy has been developed which attempts to enhance the strength by increasing the N content therein, although being close to pure titanium. However, there is a fear of generating TiN which is a representative LDI (low density inclusion) in titanium by an addition of N. Therefore, there is a restriction which requires the use of addition technology. A high-strength titanium in which the N amount is controlled can not always be a material that can be produced at a low cost.

[0007] To mention representative technologies among known technologies, a high-tensile titanium excellent in hydrogen embrittlement resistance comprises Fe of from 0.25 to 1.0%, O of from 0.45 to 1.0%, C of 0.1% or less, H of 0.015% or less, N of 0.07% or less, and the balance being substantially Ti is disclosed in JP-A No. 52-115713.

[0008] As for a titanium alloy as a magnetic disk substrate, an alloy composition comprising from 0.2 to 1.0% of at least one element of Mo, Ni, Co, Cr and Fe, and further comprising from 0.03 to 0.5% of Mo+2Ni+0.75C and the balance being substantially Ti is disclosed in JP-A No. 3-267334.

[0009] A high-strength titanium alloy for casting which comprises Fe of from 0.3 to 3.5%, O of from 0.05 to 0.95%, Cr of from 0 to 0.5%, Al of from 0 to 3.5%, V of from 0 to 3%, C of from 0 to 0.3%, Si of from 0 to 0.2%, Mn of from 0 to 0.1%, Ni of from 0 to 0.3, N of from 0 to 0.2% and the balance being Ti and unavoidable impurities is disclosed in JP-A No. 11-36029.

[0010] It is advantageous to produce a titanium alloy at a low cost when a low-grade sponge titanium can be used as a raw material. However, the low-grade sponge titanium has only been used as an additive to steel due to a large amount of impurities therein. Nevertheless, when the impurities are examined, it was found that there are many components which can be utilized for enhancing strength of titanium. Also, other components do not give any substantial influence on physical properties of the titanium alloy unless amounts thereof do not go over a given limit.

SUMMARY AND OBJECTS OF THE INVENTION

[0011] An object of the present invention is to provide a titanium alloy which can use a low-priced low-grade sponge titanium as a raw material. Further, although being a low alloy, the titanium alloy has a high strength and has realized 750 MPa or more in terms of tensile strength by actively utilizing impurities present in the low-grade sponge titanium such that the contents of O, C, N and Fe are appropriately controlled.

[0012] A high-strength low-alloy titanium alloy according to the present invention comprises O of from 0.2 to 0.8%, C of from 0.01 to 0.15%, N of from 0.01 to 0.07%, Fe of from 0.3 to 1.0% and the balance being substantially Ti and, also, has a tensile strength of 750 MPa or more.

[0013] A method for producing the high-strength low-alloy titanium alloy according to the present invention is characterized by using a low-grade sponge Ti comprising N of 0.01% or more and Fe of 0.2% or more in at least a portion of raw materials to allow it to be a source of the aforementioned Ni and Fe components.

[0014] Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0015] A high-strength low-alloy titanium alloy according to the present invention can contain not only the aforementioned alloy components which are present in a state of being added to a base metal Ti, namely, O, C, N and Fe, but also at least one element of Cr and Ni such that an entire content thereof is less than or equal to the Fe and Ni contents. On this occasion, it is necessary that the aforementioned alloy components and the Cr and/or Ni component satisfy a relation of 0.5 ≤ (Fe + Cr + Ni) ≤ 1.0%.

[0016] A function of alloy components which constitute the high-strength low-alloy titanium alloy according to the present invention and a reason why composition ranges are defined as described above are described below. It goes without saying that, since Ti is light in weight and constitutes a structural material having high strength, Ti was selected as a base metal.

[0017] O: from 0.2 to 0.8%; preferably from 0.4% to 0.7%

[0018] Fe is an effective element for enhancing strength of Ti and is added in an amount of at least 0.2% in order to secure the strength. As the amount of O to be added is increased, the strength thereof is of course increased but Ti tends to be brittle; therefore, such additional amount is restricted to be 0.8% or less. The additional amount thereof is preferably in the range from 0.4% to 0.7%.


C: from 0.01 to 0.15%; preferably from 0.05 to 0.10%

Being same as in O and N, C is a component for enhancing tensile strength. In order to obtain such effect, C is added in an amount of 0.01% or more. But, when it is added in a large amount, TiC which is a compound between C and Ti is generated to decrease fatigue strength. Therefore, the amount of C to be added is selected from amounts of at most 0.15%. From the standpoint of securing an additional effect of C and preventing the generation of TiC, the amount of C to be added is preferably in the range of from 0.05 to 0.10%.

N: from 0.01 to 0.07%; preferably from 0.02 to 0.05%

N is a component for enhancing strength. A function thereof is more remarkable than that of O. Since, in a same manner as in C as described above, N forms TiN by combining with Ti which invites a crack or decrease fatigue strength at the time of performing a plastic treatment, N is added within a limit defined by JIS, namely, in an amount of 0.07% or less. As described above, when the low-grade sponge Ti is used as a raw material, N is assuredly contained therein and it is practically difficult to allow it to be less than 0.01%. N is preferably in the range of from 0.02 to 0.05%.

Fe: from 0.3 to 1.0%; preferably from 0.5% to 1.0%

Fe is a component for not only enhancing strength but also contributing to improvement of ductility by forming a β-phase. Particularly, in order to secure an effect of improving the ductility, it is necessary to add Fe in an amount of 0.3% or more. On the other hand, Fe is an element which easily segregates. When it is added in a large amount, there is a fear of generating a fluctuation in characteristics. Therefore, an additional amount thereof is selected such that it falls within 1.0%. A low-grade sponge titanium for addition to steel contains Fe of ordinarily from 0.2 to 2.0% with an average of 0.5% and, by using this sponge titanium, Fe of from 0.3 to 1.0% can easily be contained. A preferable additional amount thereof is from 0.5% to 1.0%.

Fe+%Cr+%Ni %=1.2% or less

Ni and Cr are contained in the low-grade sponge titanium and, when the sponge titanium is used as a raw material, there is a possibility that they are unavoidably introduced. Since they have no specific meaning of presence and, when they are present in a large amount, a tough ductile property is impaired; therefore, contents thereof are controlled totally with the content of Fe.

Fe+%Cr+%Ni %=0.9%+0.1(Fe+%Cr+%Ni %): 1.0% or less

O+N+C) as a whole is useful for enhancing strength. However, when (O+N+C) is present in a large amount, the presence thereof, together with the presence of (Fe+Cr+Ni), is detrimental to the tough ductile property. Therefore, both presences are controlled. Factors attached to contents of respective components were determined in accordance with the magnitude of influence to the tough ductile property.

The high-strength low-alloy titanium alloy according to the present invention is preferably subjected to finish forming at a forging ratio of 3 or more in the temperature range of from 600 to 900° C. When a product is produced from the titanium alloy, whichever the alloy composition thereof may be, the above-described basic aspect or a modified aspect are used. By performing this finish forming, a fine grain structure in which a grain size is 30 μm or less can be obtained, thereby realizing a high ductility. The forging ratio of 3 or more is a necessary condition for granulating a β-phase to obtain an effect of the enhancement of the ductility. In regard to a temperature of the finish forming, when it is as low as less than 600° C, a flaw cannot be prevented from being generated on the product; on the other hand, when it is as high as over 900° C, a crystal grain becomes coarse and large and, then, the enhancement of the ductility cannot be expected.

Succeeding to the finish forming under the aforementioned conditions, annealing is more preferably performed at a temperature of from 650 to 900° C. By performing this annealing, granulation of the structure of the titanium alloy is promoted, thereby enhancing the effect of the ductility. When an annealing temperature is less than 650° C, a sufficient effect cannot be obtained, while, when it is over 900° C, the crystal grain becomes coarse and large and, then, the enhancement of the ductility cannot be expected.

Due to a selection of the aforementioned alloy composition, the high-strength low-alloy titanium alloy according to the present invention exhibits a high strength such that tensile strength is 750 MPa or more. This value is of a high level which is over the strength of the fourth type of the titanium bar defined by JIS and expands an area of applications of the titanium alloy. This titanium alloy can utilize a low-priced low-grade sponge titanium which has been only used as an addition to steel as a raw material and, rather, actively makes use of impurities (Fe: 0.2% or more; N: 0.01% or more) contained therein. As a result, it has become possible that a production cost of the titanium alloy is substantially reduced by the present invention.

**EXAMPLES**

Titanium alloys as shown in Table 1 were produced by melting by means of a plasma skull furnace. Nos. 1, 2, 3-1, 4, 5, and 6-1 are Examples while Nos. 3-2*, 6-2*, and 7* are Comparative Examples. At the time of such production by melting, compositions of respective alloys were different from one another, but a low-grade sponge titanium was used in 50 to 100% of raw materials. Respective titanium alloys were forged into ingots each having a diameter of 100 mm and a weight of 8 kg. Each ingot was extended while being forged at 1000° C. so as to have a diameter of 50 mm and, then, further worked at a temperature shown in Table 1 so as to obtain a round bar having a diameter of 20 mm. Thereafter, the thus-obtained round bar was subjected to annealing of heating-cooling for 2 hours at 750° C. From the resultant sample, a test piece having a diameter in a straight portion of 6.5 mm and a distance between evaluation points of 25 mm was prepared and, then, the tensile characteristics thereof were examined. The results are shown in Table 1 all together.

The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.
### TABLE 1

<table>
<thead>
<tr>
<th>No.</th>
<th>O</th>
<th>N</th>
<th>C</th>
<th>Fe</th>
<th>Cr</th>
<th>Ni</th>
<th>Formula 1</th>
<th>Formula 2</th>
<th>Finish forming temperature (°C)</th>
<th>Tensile strength (MPa)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.25</td>
<td>0.06</td>
<td>0.03</td>
<td>0.78</td>
<td>0.21</td>
<td>0.12</td>
<td>1.11</td>
<td>0.51</td>
<td>850</td>
<td>753</td>
<td>23.5</td>
</tr>
<tr>
<td>2</td>
<td>0.44</td>
<td>0.03</td>
<td>0.06</td>
<td>0.62</td>
<td>0.02</td>
<td>0.01</td>
<td>0.65</td>
<td>0.62</td>
<td>850</td>
<td>830</td>
<td>20.3</td>
</tr>
<tr>
<td>3-1</td>
<td>0.67</td>
<td>0.02</td>
<td>0.03</td>
<td>0.55</td>
<td></td>
<td></td>
<td>0.55</td>
<td>0.79</td>
<td>850</td>
<td>970</td>
<td>13.2</td>
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<tr>
<td>3-2*</td>
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<td>0.02</td>
<td>0.03</td>
<td>0.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1000</td>
<td>958</td>
<td>5.1</td>
</tr>
<tr>
<td>4</td>
<td>0.78</td>
<td>0.03</td>
<td>0.08</td>
<td>0.39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>850</td>
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</tr>
<tr>
<td>5</td>
<td>0.45</td>
<td>0.03</td>
<td>0.12</td>
<td>0.55</td>
<td>0.01</td>
<td>0.01</td>
<td>0.57</td>
<td>0.68</td>
<td>850</td>
<td>872</td>
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<td>6-1</td>
<td>0.44</td>
<td>0.04</td>
<td>0.07</td>
<td>0.43</td>
<td>0.11</td>
<td>0.05</td>
<td>0.59</td>
<td>0.64</td>
<td>850</td>
<td>860</td>
<td>17.2</td>
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<td>6-2*</td>
<td>0.44</td>
<td>0.04</td>
<td>0.07</td>
<td>0.43</td>
<td>0.11</td>
<td>0.05</td>
<td>0.59</td>
<td>0.64</td>
<td>1000</td>
<td>870</td>
<td>7.3</td>
</tr>
<tr>
<td>7*</td>
<td>0.14</td>
<td>0.01</td>
<td>0.01</td>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>850</td>
<td>450</td>
<td>33.2</td>
</tr>
</tbody>
</table>

Formula 1: Fe % + Cr % + Ni %
Formula 2: O % + 2N % + 0.5C % + 0.1(Fe % + Cr % + Ni %)

What is claimed is:

1. A high-strength low-alloy titanium alloy composition comprising O of from 0.2 to 0.8%, C of from 0.01 to 0.15%, N of from 0.01 to 0.07%, Fe of from 0.3 to 1.0% and the balance being substantially Ti and, also, having a tensile strength of 750 MPa or more.

2. The high-strength low-alloy titanium alloy composition according to claim 1, and further comprising at least one of Cr and Ni such that an entire content inclusive of Fe comes to be Fe %+Cr %+Ni %:1.2% or less, and satisfying a relation of O %+2N %+0.9%+0.1(Fe %+Cr %+Ni %):1.0% or less.

3. A method for producing a high-strength low-alloy titanium alloy composition comprising:
   - selecting O of from 0.2 to 0.8%;
   - selecting C of from 0.01 to 0.15%;
   - selecting N of from 0.01 to 0.07%;
   - selecting Fe of from 0.3 to 1.0%; and
   - providing a balance being substantially Ti for forming a high-strength low-alloy titanium alloy with a tensile strength of 750 MPa or more.

4. The method for producing the high-strength low-alloy titanium alloy as set forth in claim 1, wherein the Ti is a low-grade sponge Ti containing N of 0.01% or more and Fe of 0.2% or more in at least a portion of raw materials to allow it to be a source of Ni and the aforementioned Fe components.

5. The method for producing the high-strength low-alloy titanium alloy as set forth in claim 1, and further including the steps of:
   - selecting at least one of Cr and Ni such that an entire content inclusive of Fe comes to be Fe %+Cr %+Ni %:1.2% or less, and satisfying a relation of O %+2N %+0.9%+0.1(Fe %+Cr %+Ni %):1.0% or less.

6. The method for producing the high-strength low-alloy titanium alloy as set forth in claim 1, wherein the Ti is a low-grade sponge Ti containing N of 0.01% or more and Fe of 0.2% or more in at least a portion of raw materials to allow it to be a source of the aforementioned Ni and Fe components.

7. The method for producing the high-strength low-alloy titanium alloy as set forth in claim 1, and including the step of subjecting the titanium alloy to finish forming at a forging ratio of 3 or more in the temperature range of from 600 to 900° C.

8. The method for producing the high-strength low-alloy titanium alloy as set forth in claim 4, and including the step of subjecting the titanium alloy to finish forming at a forging ratio of 3 or more in the temperature range of from 600 to 900° C.

9. The method for producing the high-strength low-alloy titanium alloy as set forth in claim 5, and including the step of subjecting the titanium alloy to finish forming at a forging ratio of 3 or more in the temperature range of from 600 to 900° C.

10. The method for producing the high-strength low-alloy titanium alloy as set forth in claim 6, and including the step of subjecting the titanium alloy to finish forming at a forging ratio of 3 or more in the temperature range of from 600 to 900° C.

11. The method for producing the high-strength low-alloy titanium alloy as set forth in claim 3, and including the steps of:
   - subjecting the titanium alloy to finish forming at a forging ratio of 3 or more; and
   - annealing in the temperature range of from 650 to 900° C.

12. The method for producing the high-strength low-alloy titanium alloy as set forth in claim 4, and including the steps of:
   - subjecting the titanium alloy to finish forming at a forging ratio of 3 or more; and
   - annealing in the temperature range of from 650 to 900° C.

13. The method for producing the high-strength low-alloy titanium alloy as set forth in claim 5, and including the steps of:
   - subjecting the titanium alloy to finish forming at a forging ratio of 3 or more; and
   - annealing in the temperature range of from 650 to 900° C.

14. The method for producing the high-strength low-alloy titanium alloy as set forth in claim 6, and including the steps of:
   - subjecting the titanium alloy to finish forming at a forging ratio of 3 or more; and
   - annealing in the temperature range of from 650 to 900° C.