A titanium alloy is provided wherein metal boride is uniformly crystallized and/or precipitated in the matrix. The heating temperature in the finishing hot working is set smaller than the \( \beta \) transus temperature by not less than 10° C., thereby causing the matrix to include an equiaxial \( \alpha \) structure in a rate of not less than 40 vol %. This titanium alloy has excellent properties, i.e., high rigidity, ductility and fatigue strength, which are all required for structural components, and therefore can be widely applied to a mechanical component such as an engine of an automobile, a structural component in an aircraft as well as a component for a high speed rail vehicle.

<table>
<thead>
<tr>
<th>Test specimen No.</th>
<th>Classification</th>
<th>Heating temperature in finishing treatment (°C)</th>
<th>Temperature in solution treatment (°C)</th>
<th>Proof stress (MPa)</th>
<th>Strength (MPa)</th>
<th>Elongation (%)</th>
<th>Reduction (%)</th>
<th>Fatigue strength (MPa)</th>
<th>Young's modulus (GPa)</th>
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<tr>
<td>1</td>
<td>Comparative example</td>
<td>*1170</td>
<td>900</td>
<td>947</td>
<td>1137</td>
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<td>900</td>
<td>957</td>
<td>1137</td>
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<td>20.8</td>
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<td>700</td>
<td>950</td>
<td>1158</td>
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<td>20.8</td>
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</tr>
<tr>
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<td>Inventive example</td>
<td>1040</td>
<td>1050</td>
<td>948</td>
<td>1121</td>
<td>9.4</td>
<td>18.0</td>
<td>55</td>
<td>670</td>
</tr>
<tr>
<td>7</td>
<td>Comparative example</td>
<td>1040</td>
<td>1100</td>
<td>930</td>
<td>1140</td>
<td>7.2</td>
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The mark * indicates the outside the range specified by the invention.
FIG. 1

<table>
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<th>Test specimen No.</th>
<th>Classification</th>
<th>Heating temperature in finishing forging (°C)</th>
<th>Temperature in solution treatment (°C)</th>
<th>Tensile properties</th>
<th>Equiaxial rate (%)</th>
<th>Fatigue strength (MPa)</th>
<th>Young's modulus (GPa)</th>
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<tr>
<td>1</td>
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<td>947</td>
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<td>900</td>
<td>967</td>
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<td>20.8</td>
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<tr>
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<td>Inventive example</td>
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<td>900</td>
<td>967</td>
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The mark * indicates the outside the range specified by the invention.
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<th>Process No. (Classification)</th>
<th>Tensile properties</th>
<th>Fatigue strength (MPa)</th>
<th>Equiaxial rate (%)</th>
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</tr>
<tr>
<td></td>
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<tr>
<td></td>
<td>Elongation (%)</td>
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<td></td>
<td>Elongation (%)</td>
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The mark * indicates the outside the range specified by the invention.
TITANIUM ALLOY HAVING HIGH DUCTILITY, FATIGUE STRENGTH AND RIGIDITY AND METHOD OF MANUFACTURING SAME

TECHNICAL FIELD

[0001] The present invention relates to a titanium alloy having a high ductility, fatigue strength and rigidity, which alloy is used in a mechanical component requiring excellent mechanical properties and a light weight as well, for instance, a connecting rod, valve, camshaft, crankshaft and push rod in an engine of an automobile or a structural component in an aircraft, a high-speed rail vehicle or the like. The present invention also relates to a method of manufacturing such a titanium alloy.

BACKGROUND ART

[0002] A titanium alloy has excellent properties for the corrosion resistance and the heat resistance, along with a high mechanical strength and a lightweight property, so that an application of the alloy to various mechanical components in an automobile, an aircraft and a high-speed rail vehicle is now widely extending. However, titanium alloy has a relatively small Young’s modulus, i.e., about half of that in iron or steel materials. Accordingly, buckling and bending must be taken into account when the alloy is used in such a mechanical structure. For instance, when the titanium alloy is used to a mechanical component having a long axial length, such as a camshaft, a connecting rod or the like, the cross section of the component must be increased in a design work in order to obtain a required mechanical strength. However, such design work makes it impossible to effectively utilize the specific properties of the titanium alloy, i.e., the lightweight and the high mechanical strength.

[0003] In view of these facts, several investigations have been made so far to enhance the Young’s modulus of the titanium alloy by providing a composite material into which fibers or particles having a high Young’s modulus are dispersed in titanium. For instance, in Japanese Patent Application Laid-open No. 5-5142, a method of producing a titanium-based composite material has been proposed, in which a TiB solid solution is dispersed into the matrix of the titanium alloy in a predetermined volume percentage. In this specification, it has been demonstrated that the production method is capable of providing a high mechanical strength, a high rigidity, and a high wearing resistance over a wide range from room temperature to a high temperature.

[0004] However, the composite material has a less plastic workability in the production method proposed therein, and therefore the application of a melting/casting method or a powder metallurgy method is a prerequisite for this material, thereby making it impossible to employ the composite material to a large sized structural component. Moreover, the finding regarding the matrix structure in the composite material has not been disclosed, and therefore it is not clear whether or not the ductility and the fatigue strength required for such a structural element can securely be obtained with the method proposed therein.

[0005] Furthermore, in Japanese Patent Application Laid-open No. 10-1760, a particle-strengthened type titanium-based composite material has been proposed, in which material the matrix is formed by a α-β type titanium alloy including TiB or TiC particles, and the structure is controlled so as to obtain a needle-shaped α phase structure. In the composite material proposed therein, however, TiB or TiC particles are used as strengthened ceramic particles and therefore the powder metallurgy method is a prerequisite for the production method, thereby making it difficult to apply the composite material to a large-scale structural elements. In addition, the needle-shaped structure in the matrix provides a high Young’s modulus. Nevertheless, a sufficiently high ductility can hardly be obtained.

DISCLOSURE OF INVENTION

[0006] As described above, there is a problem that titanium alloy has a relatively higher mechanical strength, but a smaller Young’s modulus, compared with the iron or steel materials. Various composite materials have been produced to overcome this problem. However, no improvement has been succeeded yet to obtain a high hot workability and a high ductility.

[0007] On the other hand, it is required that the structural elements may be used in a much severer environment and the manufacturing cost may also be reduced, along with an excellent hot workability and mechanical strength. For instance, a high hot workability, a high rigidity, an excellent ductility and fatigue strength are all required for a connecting rod of an automobile, although it can be used in such a sever environment and the manufacturing cost is further reduced. Nevertheless, any titanium alloy having such properties has not developed yet.

[0008] In view of these requirements on the development of titanium alloys for such a mechanical part, it is an object of the present invention to provide titanium alloy having an excellent properties with regard to the hot workability, the ductility, the fatigue strength and the rigidity, and it is further another object of the present invention to provide a method of manufacturing such a titanium alloy. More specifically, an object of the invention is to develop a titanium alloy which is capable of hot forging or hot rolling, and which has a tensile strength not less than 1100 MPa and a Young’s modulus not less than 130 GPa, together with a provision of the ductility and fatigue strength in a predetermined magnitude.

[0009] The present inventors studied on the composition of elements, the fine particles to be dispersed and the structure in the matrix in order to develop titanium alloys having the above-mentioned properties, and obtained the following findings (a) to (c):

[0010] (a) The Young’s modulus of a titanium alloy may be effectively enhanced by dispersing particles having a high Young’s modulus into a matrix. The dispersed particles are titanium carbide or titanium boride particles, which are produced by the crystallization and/or precipitation in the matrix. In this case, titanium boride is more effective in usage, since it has 1.3 times greater Young’s modulus than titanium carbide.

[0011] (b) In a titanium alloy, various matrix structures appear even if it includes the same alloy composition. Fundamentally, these structures can be classified into the equiaxial α structure and the needle-shaped α structure. In order to obtain an excellent ductility and fatigue strength, the matrix structure must have a certain rate of equiaxial α structure.
In the formation of the equiaxial α structure in the matrix, it is necessary to carry out a thermal treatment after a working stress is applied thereto. The temperature in the hot working should be smaller than the β transus temperature. Moreover, it is preferable that the subsequent solution treatment should also be carried out at a temperature smaller than the β transus temperature.

(c) Elements Al, oxygen (O), C, H and N, which serve to stabilize the α phase, enhance the Young’s modulus of the matrix, when they are included therein at an appropriate content. Moreover, neutral type elements Sn, Zr and Hf provide a very weak effect on the enhancement of the Young’s modulus, but an appreciable effect on the enhancement of the mechanical strength at a high temperature and the creep resistance.

When an aging treatment is applied to the titanium alloy including the above-mentioned elements, Al, oxygen, or Sn, Zr, Hf, these elements provide an aged hardening property of promoting to generate an intermetallic compound (Ti₃Al), thereby enabling the fatigue strength to be greatly increased.

Complete solid solution or isomorphous type elements V and Mo among the β phase stabilizing elements greatly reduce the Young’s modulus, whereas eutectoid type elements Fe and Cr reduces not so greatly, compared with the isomorphous type elements. At any rate, the β phase stabilizing elements reduce the Young’s modulus to greater or less extent, but enhance the hot workability. Accordingly, it is desirable to add these elements to the alloy in an appropriate manner.

The present invention is realized on the basis of the above-mentioned finding, and the gist is that the following titanium alloys (1), (3) and (4), and the following methods of producing the titanium alloys (2), (3) and (4) are provided:

(1) A titanium alloy having a high ductility, fatigue strength and rigidity, wherein said titanium alloy includes B: 0.5-3.0% in mass %, and metal boride is uniformly crystalized and/or precipitated in the matrix, and wherein the matrix includes an equiaxial α structure in a rate of not less than 40 vol %. The titanium alloy is either of α type or of α+β type.

(2) A method for manufacturing a titanium alloy having a high ductility, fatigue strength and rigidity, wherein the titanium alloy includes B: 0.5-3.0% in mass %, and metal boride is uniformly crystalized and/or precipitated in the matrix, and wherein the heating temperature in the finishing hot working should be set smaller than the β transus temperature by not less than 10°C.

In the above manufacturing method, it is preferable that the solution treatment should be applied within a temperature range between (the β transus temperature–350°C) and (the β transus temperature–10°C), and, if necessary, the aging treatment should be further applied.

(3) It is preferable that the above-mentioned titanium alloy (1) or (2) further includes Al: 5.5-10%, oxygen (O): 0.07-0.25%, C: not more than 0.1%, H: not more than 0.05% and N: not more than 0.1% in weight %.

(4) Similarly, it is preferable that the above-mentioned titanium alloy (3) further includes one or more than two of Sn, Zr and Hf in not more than 20% in mass % in amount and/or one or more than two of β phase stabilizing elements in not more than 10% of V equivalent given by the below equation (a):

\[
V_{\text{equivalent}} = V + \frac{15}{10}Mo + \frac{15}{6.3}Cr + \frac{15}{4}Fe + \frac{15}{36}Nb + \frac{15}{7}Ti + \frac{15}{25}V
\]

Thus, it is preferable according to the invention that the above-mentioned titanium alloy (3) further includes one or more than two of Sn, Zr and Hf in not more than 20% in mass % in amount and/or one or more than two of β phase stabilizing elements in not more than 10% of V equivalent given by the below equation (a):

**Fig. 1** is a table representing properties after various solid solution treatments are applied to titanium alloys in Example 1 and **Fig. 2** is a table representing properties after various solid solution or aging treatments are applied to titanium alloys in Example 1.

**BEST MODE FOR CARRYING OUT THE INVENTION**

A titanium alloy according to the invention is characterized by an excellent ductility and fatigue strength of the matrix structure, in which the rate of the equiaxial α structure (hereinafter denoted by “the isometric rate”) is controlled into an area rate (the same as the volume rate) more than 40% by finely and uniformly crystalized and/or precipitating metal boride in a matrix, and, if necessary, by including one or more of the α phase stabilizing elements Al, oxygen and the like thereto.

Moreover, in the titanium alloy according to the invention, one or more of Sn, Zr and Hf is included therein to enhance the mechanical strength at high temperature and the creep resistance. Otherwise, the amount of β stabilizing elements to be added is restricted in an appropriate V equivalent so as not to form a β phase monolayer, and thus the hot workability is enhanced by decreasing the β transus temperature. In the following, the reason for the above specification will be described as for the microstructure, the element composition and the manufacturing method.

**1. Microstructure**

Titanium alloy can be classified into three types in accordance with the microstructure at normal temperature: α type; α+β type; and β type. The subject matter of the present invention extends to the α type and the α+β type.

Generally, either in the α type alloy or in the α+β type alloy, the equiaxial α structure is favorable for the ductility and the fatigue strength, compared with the needle-shaped α structure. Furthermore, in accordance with the author’s investigation, it is found that the matrix of the alloy does not always need to be entirely constituted by the equiaxial α structure, and the mixture of the needle-shaped structure transformed from the β phase therewith is allowed. However, in order to obtain a high ductility and fatigue strength in the mixed structure, it is necessary to set the rate of the equiaxial α structure, i.e., the equiaxial rate to be not less than 40% in the area rate. Furthermore, a more stable ductility and fatigue strength require an equiaxial rate of not less than 50% preferably.
The microstructure was inspected in the following steps: A specimen was collected from the matrix of the alloy and then observed after polishing and etching. The area rate of the equiaxial α structure, i.e., the equiaxial rate which is defined in the present invention, is determined by the area ratio of the equiaxial α structure to the needle-shaped structure, these structures being color-classified in the image analysis of a micrograph of the matrix. The reason of the equiaxial rate used in the present invention is due to the fact that the ductility and fatigue strength strongly depend on the area rate of the equiaxial α structure.

Element Composition

B Composition:

In order to uniformly disperse metal boride (TiB) into the matrix of titanium alloy, B is added thereto and then crystallized and/or precipitated in the course of solidification and cooling. Thereby, the Young’s modulus of the titanium alloy can be enhanced in accordance with the composite rule in proportion to the magnitude of volume in TiB particles having a greater Young’s modulus than the titanium alloy.

A B content of less than 0.5% provides a reduced amount of TiB crystallized and/or precipitated, thereby making it impossible to sufficiently enhance the Young’s modulus of the titanium alloy. On the other hand, a B content of greater than 3.0% provides an excess amount of dispersed TiB and an enhanced Young’s modulus of the matrix. Nevertheless, the hot ductility and the cold ductility are markedly reduced. Accordingly, it is preferable that the content of B to be added should be 0.5-3.0%.

α Phase Stabilizing Elements:

Either Al or oxygen is a α phase stabilizing element, and has a prominent effect of solid solution hardening, thereby causing the Young’s modulus to be greatly enhanced. Either an Al content of less than 5.5% or oxygen content of less than 0.07% provides no such sufficient effect. On the other hand, either an Al content of greater than 10% or an oxygen content of greater than 0.25% reduces the workability and the ductility. As a result, it can be stated that the content of the two elements to be included should be set preferably, Al: 5.5 to 10%; O: 0.07 to 0.25%, and more preferably Al: 7 to 9%; O: 0.07 to 0.15%.

As another α phase stabilizing element, C, H or N can be used. All of these elements reduce the ductility at normal temperature. Therefore, the upper limit of the content should be set such that C: 0.1%; H: 0.05% and N: 0.1%.

Neutral Type Elements

In the present invention, neutral type elements and/or β phase stabilizing elements may be added to the titanium alloy. In this case, any of these elements is solved in the matrix. Regarding neutral type elements Zr and Hf, most amounts of these elements can be solved in the matrix, and a very small amount of zirconium boride and hafnium boride is crystallized and/or precipitated in the matrix. However, such a very small amount of the borides provides no prominent enhancement of the Young’s modulus.

One or more than two of the neutral type elements Sn, Zr and Hf can be solved in the alloy, Sn, Zr or Hf provides no enhancement of the Young’s modulus, but enhances the effect of the solid solution strengthening to increase the mechanical strength at high temperature. More than 20% content of these elements reduces both the hot workability and the cold workability, and further increases the cost of manufacturing the alloy. Accordingly, the upper limit of the content should be 20% in amount, and preferably not more than 5%.

β Phase Stabilizing Elements

Elements V, Mo, Cr, Fe, Nb, Ni or W may be used as a β phase stabilizing element. The β phase stabilizing element included in the alloy decreases the β transus temperature and improves the hot workability. These elements are solved in the matrix and suppress an excessive generation of metallic compound (Ti₅Al), thereby enabling a greater content of Al to be solved. However, an excessive content of these elements causes the Young’s modulus to be markedly reduced. Accordingly, one or more than two of these elements should be added to the alloy within a range not more than 10% in the V equivalent given by the below equation (a), and more preferably not more than 5% in the V equivalent:

$$V_{\text{equiv}} = V + \frac{15}{10}Mo + \frac{15}{6.3}Cr + \frac{15}{40}Fe + \frac{15}{36}Nb + \frac{15}{9}Ni + \frac{15}{25}W$$

Manufacturing Process

The titanium alloy ingot is produced in the form of a compact shape of a raw material by appropriately selecting some of pure Al, electrolyzed Sn, Zr sponge, pure Hf, Al—V alloy, Al—Mo alloy and Mo, Cr, V and the like and by adding them to a titanium sponge in predetermined contents. In order to crystallize or precipitate TiB in the matrix of the titanium alloy in a dispersed state, Al boride, Fe boride or the like is used as a boron source in the raw material. Moreover, the oxygen amount in the ingot can be adjusted to some extent by appropriately selecting the type of titanium sponge. When, however, a much greater amount of oxygen is required, TiO₂ can be used as an adjusting material. The raw material thus adjusted is arc-melted either by the consumable electrode melting in a vacuum melting furnace or by the non-consumable electrode melting in a plasma arc melting to form an alloy ingot.

The titanium alloy ingot thus produced is hot worked by forging or rolling to obtain a desired microstructure, and then is appropriately heat-treated to adjust the mechanical properties. As described above, in order to generate the equiaxial α structure in the matrix, the material must undergo a proper thermal history after applying a working stress thereto.

The structure in the matrix is widely changed by the heating condition at a temperature close to the β transus temperature. The hot working at a temperature greater than the β transus temperature frequently generates the needle-shaped α structure, whereas the hot working at a temperature smaller than the β transus temperature frequently generates the equiaxial α structure. Accordingly, in the manufacturing method according to the invention, the heating temperature in the finishing hot working must be set smaller than the β transus temperature.

Since there exist the α and β phases in a mixed state within a temperature range just below the β transus
temperature, the process of cooling down to room temperature provides a mixed state of the needle-shaped structure and the equiaxial structure. As described above, in order to obtain the ductility and fatigue strength in a predetermined magnitude by adjusting the equiaxial \( \alpha \) structure at an area rate of not less than 40%, the heating temperature in the finishing hot working must be set smaller than the \( \beta \) transus temperature by not less than 10° C. There is no special limitation regarding the lower limit of the heating temperature. However, the temperature can be set greater than the lower limit temperature in the hot working. In the manufacturing method according to the invention, the heating temperature in the finishing hot working is specified such that a temperature greater than the \( \beta \) transus temperature can be used as for the heating temperature in the state of the rough work prior to the finishing work.

[0047] In other words, the hot working of the titanium alloy ingot is employed not only to produce a predetermined profile of a structural component, but also to obtain a predetermined microstructure of the matrix. As described above, the heat treatment after undergoing the working stress must be applied to generate the equiaxial \( \alpha \) structure in the matrix. Once, for example, the needle-shaped microstructure is formed, any heat treatment applied to the alloy no longer provides the equiaxial microstructure. In order to transform the needle structure of the matrix to the equiaxial structure, the hot working must again be applied after the alloy is heated at a temperature smaller than the \( \beta \) transus temperature.

[0048] In order to securely transform the needle structure of the matrix to the equiaxial structure, it is effective to provide a sufficient working stress and it is preferable that the hot working is carried out at a working rate not less than 50%. The crystallization and/or precipitation of coarse TiB particles causes the ductility and the fatigue strength to be reduced. To avoid such reduction, it is necessary to destroy the coarse particles by the hot working. In this case, the working rate should be preferably not less than 70%.

[0049] In the titanium alloy, a decreased temperature for working provides a reduction in the hot workability as well as the generation of working fractures. To obtain a proper working temperature, either a heat insulation material is coated onto the ingot, or the temperature in the circumference is appropriately increased within a temperature range for the warm working or the hot working, or the ingot is re-heated at a temperature smaller than the \( \beta \) transus temperature after the temperature is decreased.

[0050] The titanium alloy thus hot worked undergoes such a heat treatment as a solution treatment and/or an aging treatment to adjust the mechanical properties. When the temperature in the solution treatment is set smaller than the \( \beta \) transus temperature by not less than 10° C., the equiaxial \( \alpha \) structure, which is formed in the hot working, remains unchanged. In the other hand, a decreased temperature of the treatment provides no effect of the solution treatment, so that the temperature should be set not less than (the \( \beta \) transus temperature–350° C). In accordance with the invention, the solution treatment should be made preferably within a temperature range between (the \( \beta \) transus temperature–350° C) and (the \( \beta \) transus temperature–10° C), more preferably within a temperature range between (the \( \beta \) transus temperature–200° C) and (the \( \beta \) transus temperature–100° C).

[0051] Moreover, the aging treatment promotes to generate the intermetallic compound (Ti₃Al), thereby enabling the fatigue strength of the titanium alloy to be further enhanced. The conditions of the aging treatment vary from composition to composition of the alloy. It is preferable that the temperature of treatment should be 500-600° C. and the duration of treatment should be more than 5 hours.

**EXAMPLES**

[0052] The effect resulting from the invention will be described in detail, as for the case (Example 1), in which the solution treatment is carried out after the hot forging, and the case (Example 2), in which the aging treatment is further applied to the above treatment.

Example 1

[0053] A titanium alloy having the composition shown in Table 1 was arc-melted in a vacuum melting furnace to form an ingot having a 140 mm diameter. The \( \beta \) transus temperature of the titanium alloy used in the test was 1070° C.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Composition of elements (mass %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>V</td>
</tr>
<tr>
<td>7.72</td>
<td>0.41</td>
</tr>
</tbody>
</table>

[0054] By applying twice the hot forging and the solution treatment to the alloy ingot obtained under the following conditions, test pieces were produced:

[0055] 1. Rough-Forging

[0056] Size after forging: outside diameter 80 mm (working rate 68%, forging rate 3)

[0057] Heating temperature: 1170° C. (the \( \beta \) transus temperature–100° C.)

[0058] 2. Finish Forging

[0059] Size after forging: outside diameter 25 mm (working rate 90%, forging rate 10)

[0060] Heating temperature: 1040° C. to 1170° C. (the respective heating temperatures being indicated in FIG. 1)

[0061] 3. Solution Treatment

[0062] Heating temperature: 700° C. to 1100° C. (the respective heating temperatures being indicated in FIG. 1)

[0063] Heating duration: 2 hours

[0064] The tensile property at normal temperature, the fatigue strength at normal temperature and the Yong’s modulus were determined as the properties of the titanium alloy used to test after the solution treatment. Furthermore, the microstructure of each test piece was observed to determine the isometric rate (vol. %) of the matrix. The obtained results are given in FIG. 1.

[0065] From the results in FIG. 1, it is found that all the test pieces have a tensile strength of 1100 MPa or more and a Yong’s modulus of 130 Gpa or more, thereby exhibiting
a high rigidity. In particular, inventive examples No. 3 to 6 provide an isometric rate of not less than 40 vol % and further exhibit excellent properties regarding the fatigue strength and the ductility, along with high rigidity.

Example 2

Utilizing the alloy ingot obtained in Example 1, the effect of the aging treatment after the solution treatment was studied by varying the conditions of hot forging. The titanium alloys used in the test were treated according to the following processes A to D.

[0068] 1. Process A (Comparative Example)
[0069] 1-1. Finishing Forging
[0070] Size after forging: outside diameter 25 mm (working rate 97%, forging rate 30)
[0071] Heating temperature: 1170° C. (the β transus temperature+100° C.)

[0072] 1-2. Solution Treatment
[0073] Condition of treatment: 900° C.×2 hours

[0074] 2. Process B (Comparative Example)
[0075] 2-1. Finishing Forging
[0076] Size after forging: outside diameter 25 mm (working rate 97%, forging rate 30)
[0077] Heating temperature: 1170° C. (the β transus temperature+100° C.)

[0078] 2-2. Solution Treatment
[0079] Treatment condition: 900° C.×2 hours

[0080] 2-3. Aging Treatment
[0081] Treatment condition: 580° C.×8 hours

[0082] 3. Process C (Inventive Example)
[0083] 3-1. Rough-Forging
[0084] Size after forging: outside diameter 80 mm (working rate 68%, forging rate 3)
[0085] Heating temperature: 1170° C. (the β transus temperature+100° C.)

[0086] 3-2. Finishing Forging
[0087] Size after forging: outside diameter 25 mm (working rate 90%, forging rate 10)
[0088] Heating temperature: 1040° C. (the β transus temperature+30° C.)

[0089] 3-3. Solution Treatment
[0090] Treatment condition: 900° C.×2 hours

[0091] 4. Process D (Inventive Example)
[0092] 4-1. Rough-Forging
[0093] Size after forging: outside diameter 80 mm (working rate 68%, forging rate 3)

[0094] Heating temperature: 1170° C. (the β transus temperature+100° C.)

[0095] 4-2. Finishing Forging
[0096] Size after forging: outside diameter 25 mm (working rate 90%, forging rate 10)

[0097] Heating temperature: 1040° C. (the β transus temperature+30° C.)

[0098] 4-3. Solution Treatment
[0099] Treatment condition: 900° C.×2 hours

[0100] 4-4. Aging Treatment

[0101] Treatment condition: 580° C.×8 hours

The tensile property at normal temperature, the fatigue strength at normal temperature, the Young’s modulus and further the equiaxial rate (vol %) of the matrix were determined as the properties of the titanium alloy used to test after the solution treatment or the aging treatment. Furthermore, the microstructure of each test piece was observed to determine the equiaxial rate (vol. %) of the matrix. The obtained results are given in FIG. 2.

In the processes A and B of the comparative examples, a tensile strength of 1100 Mpa or more and a Young’s modulus of 130 Gpa or more were attained and a high rigidity was also obtained. However, an improper setting of the heating temperature in the finishing forging provided no sufficiently high ductility and fatigue strength. On the contrary, in the processes C and D of the inventive examples, an excellent ductility and fatigue strength were attained, along with a high rigidity. In the process D, moreover, an application of the aging treatment enhances the proof stress and tensile stress and, at the same time, greatly enhances the fatigue strength.

INDUSTRIAL APPLICABILITY

In accordance with the titanium alloy and the manufacturing method proposed in the present invention, excellent properties, i.e., the rigidity, the ductility and the fatigue strength, which are all required for a structural component can be obtained, thereby making it possible to provide mechanical components having excellent mechanical properties and a light weight as well. Accordingly, the titanium alloy according to the present invention can be widely applied to a mechanical component such as a connection rod, camshaft, crankshaft and push rod in an engine of an automobile as well as a structural element for an aircraft and parts for a high-speed rail vehicle.

1. A titanium alloy having a high ductility, fatigue strength and rigidity, wherein said titanium alloy includes B: 0.5-3.0% in mass %, and metal boride is uniformly crystallized and/or precipitated in the matrix, and wherein the matrix includes an equiaxial α structure in a rate of not less than 40 vol %.

2. A titanium alloy having a high ductility, fatigue strength and rigidity according to claim 1, wherein said titanium alloy is either of α type or of α+β type.

3. A titanium alloy having a high ductility, fatigue strength and rigidity according to claim 1, wherein said titanium alloy further includes Al: 5.5-10%, oxygen (O): 0.07-0.25%, C: not more than 0.1%, H: not more than 0.05% and N: not more than 0.1% in mass %.
4. A titanium alloy having a high ductility, fatigue strength and rigidity according to claim 3, wherein said titanium alloy further includes one or more than two of Sn, Zr and Hf in not more than 20% in mass % in amount and/or one or more than two of β phase stabilizing elements in not more than 10% of V equivalent given by the below equation (a):

\[ V_{\text{equivalent}} = V + \frac{15}{10} \times Mo + \frac{15}{6.3} \times Cr + \frac{15}{4.0} \times Fe + \frac{15}{36} \times Nb + \frac{15}{9} \times Ni + \frac{15}{25} \times W \]  

\[ (a) \]

5. A method for manufacturing a titanium alloy having a high ductility, fatigue strength and rigidity, wherein said titanium alloy includes B: 0.5-3.0% in mass %, and metal boride is uniformly crystallized and/or precipitated in the matrix, and wherein the heating temperature in the finishing hot working is set smaller than the β transus temperature by not less than 10° C.

6. A method for manufacturing a titanium alloy having a high ductility, fatigue strength and rigidity according to claim 5, wherein the solution treatment is carried out within a temperature range between (the β transus temperature–350° C) and (the β transus temperature–10° C).

7. A method for manufacturing a titanium alloy having a high ductility, fatigue strength and rigidity according to claim 6, wherein the aging treatment is further carried out.

8. A method for manufacturing titanium alloy having a high ductility, fatigue strength and rigidity, wherein said titanium alloy includes B: 0.5-3.0%, Al: 5.5-10%, oxygen (O): 0.07-0.25%, C: not more than 0.1%, H: not more than 0.05% and N: not more than 0.1% in mass %, and metal boride is uniformly crystallized and/or precipitated in the matrix, and wherein the heating temperature in the finishing hot working is set smaller than the β transus temperature by not less than 10° C.

9. A method for manufacturing a titanium alloy having a high ductility, fatigue strength and rigidity according to claim 8, wherein the solution treatment is carried out within a temperature range between (the β transus temperature–350° C) and (the β transus temperature–10° C).

10. A method for manufacturing a titanium alloy having a high ductility, fatigue strength and rigidity according to claim 9, wherein the aging treatment is further carried out.

11. A method for manufacturing a titanium alloy having a high ductility, fatigue strength and rigidity, wherein said titanium alloy includes B: 0.5-3.0%, Al: 5.5-10%, oxygen (O): 0.07-0.25%, C: not more than 0.1%, H: not more than 0.05% and N: not more than 0.1% in mass %, and further includes one or more than two of Sn, Zr and Hf in not more than 20% in mass % in amount and/or one or more than two of β phase stabilizing elements in not more than 10% of V equivalent given by the below equation (a), and wherein the heating temperature in the finishing hot working is set smaller than the β transus temperature by not less than 10° C:

\[ V_{\text{equivalent}} = V + \frac{15}{10} \times Mo + \frac{15}{6.3} \times Cr + \frac{15}{4.0} \times Fe + \frac{15}{36} \times Nb + \frac{15}{9} \times Ni + \frac{15}{25} \times W \]  

\[ (a) \]

12. A method for manufacturing a titanium alloy having a high ductility, fatigue strength and rigidity according to claim 11, wherein the solution treatment is carried out within a temperature range between (the β transus temperature–350° C) and (the β transus temperature–10° C).

13. A method of manufacturing a titanium alloy having a high ductility, fatigue strength and rigidity according to claim 12, wherein the aging treatment is further carried out.

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May 8, 2003