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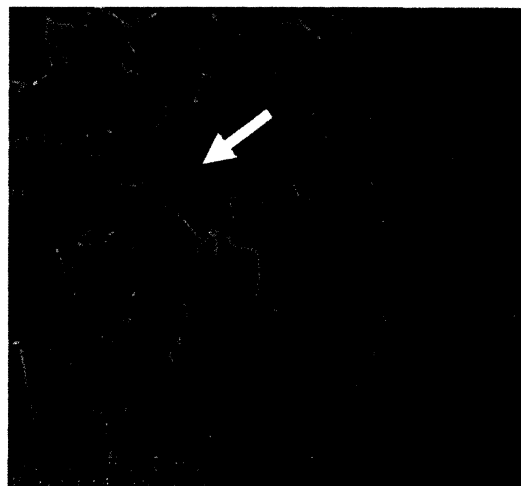
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(54) **ALPHA-BETA TITANIUM ALLOY**

(57) To provide an α - β titanium alloy that has high strength and excellent hot workability of the level of the α - β titanium alloy, typified by the Ti-6Al-4V, while exhibiting more excellent machinability than the Ti-6Al-4V. The α - β titanium alloy includes, in percent by mass: at least one element of 0.1 to 2.0% of Cu and 0.1 to 2.0% of Ni; 2.0 to 8.5% of Al; 0.08 to 0.25% of C; and 1.0 to 7.0% in total of at least one element of 0 to 4.5% of Cr and 0 to 2.5% of Fe, with the balance being Ti and inevitable impurities.

Fig. 1



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Description

Technical Field

5 **[0001]** The present invention relates to an α - β titanium alloy. More particularly, the present invention relates to an α - β titanium alloy with excellent machinability.

Background Art

10 **[0002]** A high-strength α - β titanium alloy, typified by Ti-6Al-4V, can have its strength level changed easily by a heat treatment, in addition to being lightweight and having high strength and high corrosion resistance. For this reason, this type of α - β titanium alloy has been hitherto used very often, especially in the aircraft industry. To further make use of these characteristics, in recent years, applications of the α - β titanium alloy have been increasingly expanded into the fields of consumer products, including vehicle parts, such as engine members of automobiles or motorcycles, sporting
15 goods such as golf goods, materials for civil engineering and construction, various working tools, and spectacle frames, the development fields of deep sea and energy, and the like.

[0003] For example, as such an α - β titanium alloy, Patent Document 1 mentions an α - β titanium alloy extruded material with excellent fatigue strength and a manufacturing method for the α - β titanium alloy extruded material. Specifically, the α - β titanium alloy extruded material includes specified contents of C and Al, and also includes 2.0 to 10.0% in total of
20 one or more of V, Cr, Fe, Mo, Ni, Nb, and Ta, in which an area ratio of a primary α -phase is within a certain range, a direction of a major axis of each of 80% or more of primary α grains in the primary α -phase is positioned within a specified angle range, and an average minor axis of α grains in a secondary α -phase is 0.1 μ m or more.

[0004] As the α - β titanium alloy with enhanced forgeability, Patent Document 2 mentions an α - β titanium alloy for casting that has higher strength and more excellent castability than a Ti-6Al-4V alloy. Specifically, this α - β titanium alloy
25 mentioned includes specified contents of Al, Fe + Cr + Ni, and C + N + O, and further a specified content of V if needed, with the balance being Ti and inevitable impurities.

[0005] However, the α - β titanium alloy has extremely high manufacturing cost, and in addition, especially bad machinability, which interferes with the expansion of the applications of the α - β titanium alloy. The usage range is limited in practice. In view of such circumstances, various titanium alloys with improved machinability have been recently proposed.

30 **[0006]** For example, Patent Document 3 mentions a titanium alloy for a connecting rod that has improved the machinability while suppressing the reduction in toughness and ductility by containing rare earth elements (REM) and Ca, S, Se, Te, Pb, and Bi as appropriate to form granular compounds. Patent Document 4 mentioned a free-cutting titanium alloy that has improved the machinability by containing a rare earth element and improved the hot workability by containing B.

[0007] Patent Document 5 mentions a free-cutting titanium alloy that achieves the reduction in ductility of a matrix and
35 the refinement of inclusions to improve the free cutting properties, while suppressing the reduction in the fatigue strength and ensuring hot workability, by adding P and S, P and Ni, or P, S and Ni, or further REM in addition to these elements as free-cutting component.

[0008] Further, Patent Document 6 mentions an α - β titanium alloy with excellent machinability and hot working. The α - β titanium alloy includes specified contents of C and Al and 2.0 to 10% in total of one or more elements selected from
40 the group of β -stabilizing elements consisting of respective specified contents of V, Cr, Fe, Mo, Ni, Nb, and Ta, with the balance being Ti and impurities. In the titanium alloy, an average area ratio of TiC precipitates in a microstructure is 1% or less, and an average value of the average circle equivalent diameter of the TiC precipitates is 5 μ m or less.

Prior Art Document

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Patent Document

[0009]

50 Patent Document 1: JP 2012-52219 A
Patent Document 2: JP 2010-7166 A
Patent Document 3: JP 06-99764 B
Patent Document 4: JP 06-53902 B
Patent Document 5: JP 2626344 B1
55 Patent Document 6: JP 2007-84865 B

Disclosure of the Invention

Problems to be Solved by the Invention

[0010] In the methods like Patent Documents 3 and 4 mentioned above, metallic inclusions are precipitated by using REM. In the method like Patent Document 5 mentioned above, P is positively contained to form a P inclusion. In the method like Patent Document 6, the size of a TiC precipitate is controlled. However, in these methods, it is considered that precipitation of these precipitates and inclusions are more likely to be affected by the temperatures and cooling rates of melting to forging steps, thus making it difficult to control the size of the precipitate or the like. Furthermore, the shape or size of a raw material tends to cause variations in the size or the like of the precipitate or inclusion. Thus, to achieve the excellent machinability by precipitating inclusions of interest, there is a problem that strict control of a manufacturing process is necessary.

[0011] The present invention has been made in view of the foregoing circumstance, and it is an object of the present invention to achieve an α - β titanium alloy that has high strength and excellent hot workability of the level of the α - β titanium alloy, typified by the Ti-6Al-4V, while exhibiting more excellent machinability than the Ti-6Al-4V, without the necessity for the strict control or the like of the manufacturing process.

Means for Solving the Problems

[0012] An α - β titanium alloy according to the present invention, which can solve the above-mentioned problem, is characterized by including, in percent by mass: at least one element of 0.1 to 2.0% of Cu and 0.1 to 2.0% of Ni; 2.0 to 8.5% of Al; 0.08 to 0.25% of C; and 1.0 to 7.0% in total of at least one element of 0 to 4.5% of Cr and 0 to 2.5% of Fe, with the balance being Ti and inevitable impurities.

[0013] The α - β titanium alloy may further include, in percent by mass: more than 0% and 10% or less in total of one or more elements selected from the group consisting of more than 0% and 5.0% or less of V; more than 0% and 5.0% or less of Mo; more than 0% and 5.0% or less of Nb; and more than 0% and 5.0% or less of Ta.

[0014] The α - β titanium alloy may further include, in percent by mass, more than 0% and 0.8% or less of Si.

Effects of the Invention

[0015] Accordingly, the present invention can provide the α - β titanium alloy that has high strength and excellent hot workability, such as forgeability, of the level of an α - β titanium alloy, typified by the Ti-6Al-4V, and also exhibits more excellent machinability than the Ti-6Al-4V, making it possible to ensure satisfactory lifetime of working tools.

Brief Description of the Drawings

[0016] Fig. 1 is a photomicrograph of a titanium alloy according to the present invention.

Mode for Carrying Out the Invention

[0017] The inventors have intensively studied to solve the foregoing problems. As a result, it has been found that especially, a specified content of at least one of Cu and Ni is contained in a titanium alloy, thereby significantly improving the ductility of the titanium alloy at high temperatures. In particular, thin chips are formed on the titanium alloy during a cutting process due to the reduction in deformation resistance, leading to a reduced cutting resistance, i.e., improving the machinability thereof. The composition of the α - β titanium alloy according to the present invention will be described in sequence below, starting from Cu and Ni, which are the features of the present invention.

At least one element of Cu: 0.1 to 2.0%, and Ni: 0.1 to 2.0%

[0018] These elements are solid-soluted into the α -phase and the β -phase in the alloy, thereby increasing its ductility at a high temperature and improving the hot workability. Thus, especially, the cutting resistance of the titanium alloy becomes lower, and the machinability thereof is improved. These elements may be used alone or in combination. If the content of each of these elements is less than 0.1%, the effect of improving the ductility is lessened. Thus, the content of each of these elements is set at 0.1% or more. The content of each of these elements is preferably 0.3% or more, and more preferably 0.5% or more. In contrast, if the content of each of these elements exceeds 2.0% by mass, the hardness of the titanium alloy is increased, thereby making it more likely to reduce the machinability and the hot workability, such as forgeability. Thus, the content of each of these elements is set at 2.0% or less. The content of each of these elements is preferably 1.5% or less, and more preferably 1.0% or less.

Al: 2.0 to 8.5%

[0019] Al is an α -stabilizing element and thus is contained in the titanium alloy to form the α -phase. If the Al content is less than 2.0%, the formation of the α -phase is lessened, failing to obtain sufficient strength. Thus, the Al content is set at 2.0% or more. The Al content is preferably 2.2% or more, and more preferably 3.0% or more. Meanwhile, if the Al content exceeds 8.5% to become excessive, the ductility of the titanium alloy is degraded. Thus, the Al content is set at 8.5% or less. The Al content is preferably 8.0% or less, more preferably 7.0% or less, and still more preferably 6.0% or less.

C: 0.08 to 0.25%

[0020] C is an element that exhibits the effect of improving the strength of the titanium alloy. To exhibit such an effect, the C content needs to be 0.08% or more. The C content is preferably 0.10% or more. Meanwhile, if the C content exceeds 0.25%, coarse TiC particles not solid-soluted in the α -phase will remain, thus degrading the mechanical properties of the titanium alloy. Therefore, the C content is set at 0.25% or less. The C content is preferably 0.20% or less.

1.0 to 7.0% in total of at least one element of Cr: 0 to 4.5% and Fe: 0 to 2.5%

[0021] These elements are β -stabilizing elements. These elements may be used alone or in combination. To exhibit the above-mentioned effects, the total content of these elements needs to be 1.0% or more. The total content of these elements is preferably 2.0% or more and more preferably 3.0% or more. The lower limit of the total content of these elements only needs to be 1.0% or more as mentioned above, and the lower limit of the content of each of these elements is not limited specifically. Regarding the lower limit of the content of the individual element, for example, when Cr is contained in the titanium alloy, the lower limit of Cr content can be set at 0.5% or more, and further 1.0% or more. When Fe is contained in the titanium alloy, the lower limit of Fe content can be set at 0.5% or more, and further 1.0% or more.

[0022] In contrast, when the total content of these elements is excessive, the ductility of the titanium alloy is degraded. Thus, the total content of these elements is set at 7.0% or less. The total content of these elements is preferably 5.0% or less, and more preferably 4.0% or less. Even when the total content of these elements is within the above-mentioned total content range, if the Fe content is excessive, the degradation in the ductility becomes significant. Thus, the Fe content should be restrained to 2.5% or less. The Fe content is preferably 2.0% or less. Meanwhile, if the Cr content is excessive, the machinability of the titanium alloy is degraded. Thus, the Cr content is set at 4.5% or less. The Cr content is preferably 4.0% or less, and more preferably 3.0% or less.

[0023] The α - β titanium alloy according to the present invention contains the above-mentioned components, with the balance being Ti and inevitable impurities. The inevitable impurities may include P, N, S, O, and the like. In the α - β titanium alloy according to the present invention, the P content is restrained to 0.005% or less; the N content is restrained to 0.05% or less; the S content is restrained to 0.05% or less; and the O content is restrained to 0.25% or less. The α - β titanium alloy according to the present invention may further contain the following elements.

[0024] More than 0% and 10% or less in total of one or more elements selected from the group consisting of V: more than 0% and 5.0% or less, Mo: more than 0% and 5.0% or less, Nb: more than 0% and 5.0% or less, and Ta: more than 0% and 5.0% or less

[0025] These elements are β -stabilizing elements. These elements may be used alone or in combination. To form a β -phase, the total content of these elements is preferably 2.0% or more and more preferably 3.0% or more. As long as the total content of these elements is more than 0%, the lower limit of the content of the individual element is not limited specifically. Regarding the lower limit of the content of the individual element, for example, when V is contained in the titanium alloy, the lower limit of V content can be set at 0.5% or more, and further 2.0% or more. When Mo is contained in the titanium alloy, the lower limit of Mo content can be set at 0.1% or more, and further 1.0% or more. When Nb is contained in the titanium alloy, the lower limit of Nb content can be set at 0.1% or more, and further 1.0% or more. When Ta is contained in the titanium alloy, the lower limit of Ta content can be set at 0.1% or more, and further 1.0% or more.

[0026] In contrast, if the total content of these elements is excessive, the ductility of the titanium alloy is degraded. Thus, the total content of these elements is preferably 10% or less and more preferably 5.0% or less. Even when the total content of these elements is within the above-mentioned range, if the content of at least one element of them is excessive, the ductility of the titanium alloy is degraded. Thus, the upper limit of the content of any of these elements is preferably 5.0% or less. The content of any of these elements is more preferably 4.0% or less.

Si: more than 0% and 0.8% or less

[0027] Si acts to precipitate Ti_5Si_3 in the titanium alloy. During cutting, stress is concentrated on the Ti_5Si_3 , causing voids from Ti_5Si_3 as a starting point, which makes it easy to separate chips. Consequently, the cutting resistance is

supposed to be reduced. To efficiently exhibit this effect, the Si content is preferably 0.1% or more, and more preferably 0.3% or more.

[0028] Meanwhile, if the Si content is excessive, the strength of the titanium alloy becomes extremely high, whereby a working tool might be worn significantly or broken, which makes it difficult to cut the titanium alloy. Accordingly, the Si content is set at 0.8% or less. The Si content is more preferably 0.7% or less, and still more preferably 0.6% or less.

[0029] The titanium alloy according to the present invention has the microstructure at room temperature that is composed of the α -phase and the β -phase, or the α -phase, the β -phase, and a third-phase, such as Ti_2Cu or Ti_2Ni . When Si is contained in the titanium alloy, Ti_5Si_3 is precipitated in the titanium alloy as mentioned above.

[0030] A manufacturing method for the α - β titanium alloy is not limited specifically. However, the α - β titanium alloy can be manufactured, for example, by the following method. That is, the α - β titanium alloy is manufactured by smelting titanium alloy material with the above-mentioned components, casting to produce an ingot, and then performing hot working, i.e., hot forging or hot-rolling on the ingot, followed by annealing as needed. The above-mentioned hot working involves: heating the ingot in a temperature range of a β -transformation temperature T_β to approximately $(T_\beta + 250)^\circ C$, followed by rough forging or rough rolling at a processing ratio of approximately 1.2 to 4.0, which is represented by "original cross-sectional area/cross-sectional area after the hot working"; and then performing finish processing at a processing ratio of 1.7 or more in a temperature range of approximately $(T_\beta - 50)$ to $800^\circ C$. After the above-mentioned finish processing, annealing may be performed at a temperature of 700 to $800^\circ C$ as needed. The annealing is performed, for example, for two to 24 hours. Then, an aging treatment may be performed as needed.

[0031] Note that the above-mentioned T_β is determined from the formula (1) below. The formula (1) below corresponds to formulas (1) to (3) mentioned in Morinaga et al., "Titanium alloy design using d electron theory", Light metal, Vol. 42, No. 11 (1992), p. 614-621.

$$Bo_{ave} = 0.326Md_{ave} - 1.95 \times 10^{-4}T_\beta + 2.217 \quad (1)$$

In the formula (1), the respective symbols mean the following:

$$Bo_{ave} = \sum Xi \cdot (Bo)_i \quad (2)$$

$$Md_{ave} = \sum Xi \cdot (Md)_i \quad (3)$$

where T_β is the β -transformation temperature (K).

[0032] When each element is represented as an element i in the formula (2), Bo_{ave} is an average value of a bond order Bo of the element i , Xi is an atomic ratio of the element i , and $(Bo)_i$ is a value of the bond order Bo of the element i .

[0033] When each element is represented as an element i in the formula (3), Md_{ave} is an average value of a d-orbital energy parameter Md of the element i , Xi is an atomic ratio of the element i , and $(Md)_i$ is a value of the d-orbital energy parameter Md of the element i .

[0034] The bond order Bo and the d-orbital energy parameter Md of each element are mentioned in Table 1 at p.616 of the above-mentioned reference. Xi is determined from the composition. From these data, Bo_{ave} and Md_{ave} of each element including Ti are determined and substituted into the above-mentioned formula (1), thereby making it possible to calculate a T_β . Note that this reference does not have data on Bo and Md of C. However, since the C content in the present invention is small, C is neglected to calculate the T_β .

[0035] This application claims priority based on Japanese Patent Application No. 2015-064275 filed on March 26, 2015, and Japanese Patent Application No. 2016-009417 filed on January 21, 2016, the disclosure of which is incorporated by reference herein.

Examples

[0036] The present invention will be more specifically described below by way of Examples, but is not limited to the following Examples. It is obvious that various modifications can be made to these examples as long as they are adaptable to the above-mentioned and below-mentioned concepts and are included within the scope of the present invention.

[First Example]

[0037] Test materials were fabricated in the following way. The titanium alloy with each composition shown in Table

1 below was processed by button arc melting to manufacture an ingot with a size of about 40 mm in diameter $\times$ 20 mm in height. In any example, the P content was restrained to 0.005% or less; the N content was restrained to 0.05% or less; the S content was restrained to 0.05% or less; and the O content was restrained to 0.25% or less. In Table 1, the mark "-" means that the corresponding element was not contained. The ingot was heated to 1,200°C and subjected to the rough forging at a processing ratio of 2.4, represented by the "original cross-sectional area/cross-sectional area after the hot working", followed by forging at a processing ratio of 4.4 at 870 °C to perform finish processing. Thereafter, annealing was performed on the forged material by holding it at 750°C for 12 hours, thereby producing a test material. Note that as shown in Comparative Example 7 of Table 1 below, a test material in which a crack occurred by the rough forging was not subjected to the finish forging.

Evaluation on Forgeability

[0038] In this example, the hot workability was evaluated by the hot forgeability. In detail, the presence or absence of a crack in each of forging steps, namely, the rough forging and the finish forging mentioned above, was evaluated. That is, the surface of the above-mentioned test material after each forging step was visually observed. The test materials having any crack were rated as NG, while the test materials having no cracks were rated as OK. Then, the test materials rated as OK in terms of both the rough forging and the finish forging were evaluated to have excellent forgeability.

Evaluation on Machinability

[0039] The test materials having good forgeability were evaluated for the machinability as follows. That is, a test specimen with the size below was taken out of the above-mentioned test material, and a cutting test was performed on the test specimen on the cutting conditions below. The machinability was evaluated as an average cutting resistance by measuring a cutting resistance in the cutting direction with a Kessler's cutting dynamometer, Model: 9257 B, from the start to the end of cutting and then determining an average value of the cutting resistance from the start to the end of the cutting. When performing the cutting test on Ti-6Al-4V as a general α - β titanium alloy on the same conditions, an average cutting resistance was 180 N. Because of this, in the first example, the test materials having an average cutting resistance of lower than 180 N were evaluated to be superior in the machinability, while the test materials having an average cutting resistance of 180 N or higher were evaluated to be inferior in the machinability.

Cutting Conditions

[0040]

Test Specimen: 10 mm in height $\times$ 10 mm in width $\times$ 150 mm in length
Tool: Carbide tip S30T (nose 0.4 mm) manufactured by Sandvik Corporation

End mill R390 manufactured by Sandvik Corporation (20 mm in diameter, one blade)

Cutting speed Vc: 100 m/min
Cutting amount in the axial direction: 1.2 mm
Cutting amount in the radial direction: 1 mm
Feeding speed: 0.08 mm/blade
Cutting length: 150 mm
Cutting oil: None

Measurement of Tensile Strength

[0041] The tensile strength of the α - β titanium alloy according to the present invention was also measured for reference. In detail, the titanium alloys of Examples 1 and 3, and Comparative Example 1 were used and subjected to the tensile test on the following conditions of the shape and testing speed of the test specimen. As a result, the test materials had a strength of 948 MPa in Example 1, 1,125 MPa in Example 3, and 948 MPa in Comparative Example 1, all of these strengths being relatively high. Specifically, the strengths of these test materials exhibited higher strength than the strength of 896 MPa of an annealed material of Ti-6Al-4V as a general α - β titanium alloy.

Shape of Test Specimen: ASTM E8/E8M Fig. 8 Specimen 3
Test Speed: 4.5 mm/min

[0042] The evaluation result of the above-mentioned forgeability and an average cutting resistance are also shown in Table 1.

[Table 1]

	Composition (% by mass) Balance being Ti and inevitable impurities							T_{β} (°C)	Forgeability		Average cutting resistance (N)
	Cu	Ni	Si	Al	C	Cr	Fe		Rough forging	Finish forging	
Example 1	0.5	0.5	-	4.5	0.10	2.5	1.2	976	OK	OK	148
Example 2	1.0	1.0	-	4.5	0.10	2.5	1.2	974	OK	OK	170
Example 3	2.0	2.0	-	4.5	0.10	2.5	1.2	969	OK	OK	167
Example 4	-	0.5	-	4.5	0.10	-	1.2	1,010	OK	OK	129
Example 5	0.5	0.5	-	4.5	0.10	-	1.2	1,011	OK	OK	148
Example 6	-	1.0	-	4.5	0.10	-	1.2	1,006	OK	OK	140
Example 7	1.0	1.0	-	4.5	0.10	-	1.2	1,009	OK	OK	146
Example 8	2.0	2.0	-	4.5	0.10	-	1.2	1,004	OK	OK	155
Comparative Example 1	-	-	-	4.5	0.10	2.5	1.2	979	OK	OK	199
Comparative Example 2	-	3.0	-	4.5	0.10	2.5	1.2	957	OK	OK	229
Comparative Example 3	3.0	3.0	-	4.5	0.10	2.5	1.2	965	OK	OK	241
Comparative Example 4	4.0	-	-	4.5	0.10	2.5	1.2	989	OK	NG	-
Comparative Example 5	6.0	-	-	4.5	0.10	2.5	1.2	994	OK	OK	234
Comparative Example 6	4.0	4.0	-	4.5	0.10	2.5	1.2	960	OK	OK	261
Comparative Example 7	6.0	6.0	-	4.5	0.10	2.5	1.2	950	NG	-	-

[0043] Table 1 shows the following. All Examples 1 to 8 satisfied the composition specified by the present invention and were found to enable good forging and to have excellent forgeability. Furthermore, these examples were found to have a lower average cutting resistance than that of Ti-6Al-4V as a general α - β titanium alloy and also to have good machinability.

[0044] In contrast, all Comparative Examples 1 to 7 did not satisfy the composition specified by the present invention and thereby were consequently inferior in forgeability or machinability. In detail, in Comparative Example 1, neither Cu nor Ni was contained, resulting in a high average cutting resistance. Comparative Example 1 had the same composition as that mentioned in Patent Document 6. The comparison of the above-mentioned Examples 1 to 3 with Comparative Example 1 in which the constituent elements, other than Cu and Ni, and their contents are the same as those in Examples 1 to 3 shows that in order to surely obtain good machinability by sufficiently decreasing the average cutting resistance, it is necessary to contain a specified content of at least one of Cu and Ni, as mentioned in the present invention.

[0045] In Comparative Example 2, which contained Ni, the Ni content was excessive. In Comparative Example 5, which contained Cu, the Cu content was excessive. In both examples, the average cutting resistance was higher than 180 N, resulting in bad machinability. In Comparative Examples 3 and 6, the respective contents of Cu and Ni were excessive. In both comparative examples, the average cutting resistance was higher than 180 N, resulting in bad machinability.

[0046] In Comparative Example 4, since the Cu content was excessive, the forgeability was degraded. In Comparative Example 7, since the respective contents of Cu and Ni were drastically excessive, cracking occurred at the stage of the rough forging, resulting in degradation in the forgeability.

[Second Example]

[0047] In the second example, the influence of the Si content, especially, on the machinability were studied. As shown in Table 2, various ingots with different Si contents were manufactured to produce test materials in the same way as that in the first example. In any example, the P content was restrained to 0.005% or less; the N content was restrained to 0.05% or less; the S content was restrained to 0.05% or less; and the O content was restrained to 0.25% or less. In Table 2, the mark "-" means that the corresponding element was not contained.

[0048] Each of the above-mentioned test materials was used to confirm the presence or absence of a precipitation phase, as mentioned below, and the Vickers hardness of the test material was measured as an index of strength in the second example. Furthermore, the forgeability of the test material was evaluated in the same way as that in the first example, and the machinability thereof was evaluated as mentioned below. For reference, the tensile strength of test material No. 3 in Table 2 was measured in the same way as that in the first example. This test material No. 3 had a tensile strength of 968 MPa, which was higher than a strength, i.e., 896 MPa of an annealed material of Ti-6Al-4V as the general α - β titanium alloy.

Evaluation on Presence or Absence of Precipitation Phase

[0049] The cross section of the test material was polished to a mirror-smooth state, followed by acid treatment using hydrofluoric acid to an extent that crystal grain boundaries could be seen, and then visually observed at ten field of views, each field of view having a size of $40\ \mu\text{m} \times 40\ \mu\text{m}$, with a field emission-scanning electron microscope (FE-SEM) at a magnification of 4,000 times. The test materials in which the precipitation phase with a circle equivalent diameter of $2\ \mu\text{m}$ or more was recognized at five or more of the above-mentioned ten field of views in total were evaluated to be in the "presence" of the precipitation phase. The test materials in which the precipitation phase was recognized at four or less of the above-mentioned ten field of views in total were evaluated to be in the "absence" of the precipitation phase. Note that the above-mentioned precipitation phase was separately recognized as Ti_5Si_3 by an X-ray diffraction (XRD).

[0050] Fig. 1 shows one example of a photomicrograph observed with the above-mentioned microscope. Fig. 1 is one obtained by measurement of the test material No. 3 shown in Table 2, with an arrow indicating one precipitation phase.

Measurement of Vickers Hardness HV

[0051] A Vickers hardness HV was measured at five sites of each test material on the condition of a load 10 kgf, and the measured values were averaged. In this way, an average value of the Vickers hardness was determined.

Evaluation on Machinability

[0052] The test materials evaluated to have good forgeability in the same way as that in the first example, that is, all examples shown in Table 2 were evaluated for the machinability as follows. That is, a test specimen with the size mentioned below was taken out of the above-mentioned test material, and a cutting test was performed on the test specimen on the cutting conditions below. The machinability was evaluated as an average cutting resistance by measuring a cutting resistance in the cutting direction by the Kessler's cutting dynamometer, Model: 9257 B, from the start to the end of cutting and then determining an average value of the cutting resistance from the start to the end of the cutting. When performing the cutting test on Ti-6Al-4V as the general α - β titanium alloy on the same conditions, an average cutting resistance was 122 N. Because of this, in the second example, the test materials having an average cutting resistance of lower than 122 N were evaluated to be superior in the machinability, while the test materials having an average cutting resistance of 122 N or higher were evaluated to be inferior in the machinability.

Cutting Conditions

[0053]

Test Specimen: 10 mm in height $\times$ 10 mm in width $\times$ 60 mm in length

Tool: Carbide tip S30T (nose 0.4 mm) manufactured by Sandvik Corporation

End mill R390 manufactured by Sandvik Corporation (20 mm in diameter, one blade)

Cutting speed Vc: 100 m/min

Cutting amount in the axial direction: 1.2 mm

Cutting amount in the radial direction: 1 mm

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Feeding speed: 0.08 mm/blade

Cutting length: 15 mm

Cutting oil: None

5 **[0054]** These results are also shown in Table 2.

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[Table 2]

No.	Composition (% by mass) Balance being Ti and inevitable impurities							T_{β} (°C)	Precipitation phase	HV	Forgeability		Average cutting resistance (N)
	Cu	Ni	Si	Al	C	Cr	Fe				Rough forging	Finish forging	
1	0.5	0.5	-	4.5	0.10	2.5	1.2	976	Absent	298	OK	OK	111
2	0.5	0.5	0.1	4.5	0.10	2.5	1.2	993	Present	316	OK	OK	99
3	0.5	0.5	0.3	4.5	0.10	2.5	1.2	1,027	Present	320	OK	OK	105
4	0.5	0.5	0.8	4.5	0.10	2.5	1.2	1,110	Present	335	OK	OK	112
5	0.3	0.3	0.3	4.5	0.10	2.5	1.2	1,028	Present	316	OK	OK	106
6	2.0	2.0	0.5	4.5	0.10	2.5	1.2	1,054	Present	365	OK	OK	120
7	2.0	2.0	1.0	4.5	0.10	2.5	1.2	1,137	Present	380	OK	OK	134
8	2.0	2.0	2.0	4.5	0.10	2.5	1.2	1,303	Present	397	OK	OK	Measurement was impossible due to damage to a working tool

[0055] Table 2 shows the following. That is, as clearly shown, the test material No. 1 having the same composition as that in Example 1 of Table 1 were compared with test materials No. 2 to 6, particularly, test materials No. 2 to 4 in which the contents of elements other than Si were the same as those in Example 1 of Table 1. Based on the comparison, the arrangement that contains Si in the titanium alloy made it possible to further reduce the average cutting resistance and to ensure the sufficiently high machinability, compared to a case in which Si was not contained. In contrast, when the Si content was excessive, like the test materials No. 7 and No. 8, the hardness of the titanium alloy becomes extremely high, increasing the average cutting resistance and also causing inconveniences, such as a damage of a working tool.

Claims

1. An α - β titanium alloy comprising, in percent by mass:

at least one element of 0.1 to 2.0% of Cu and 0.1 to 2.0% of Ni;

2.0 to 8.5% of Al;

0.08 to 0.25% of C; and

1.0 to 7.0% in total of at least one element of 0 to 4.5% of Cr and 0 to 2.5% of Fe, with the balance being Ti and inevitable impurities.

2. The α - β titanium alloy according to claim 1, further comprising, in percent by mass:

more than 0% and 10% or less in total of one or more elements selected from the group consisting of more than 0% and 5.0% or less of V; more than 0% and 5.0% or less of Mo; more than 0% and 5.0% or less of Nb; and more than 0% and 5.0% or less of Ta.

3. The α - β titanium alloy according to claim 1 or 2, further comprising, in percent by mass, more than 0% and 0.8% or less of Si.

Fig. 1



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/058247

A. CLASSIFICATION OF SUBJECT MATTER

C22C14/00(2006.01)i, C22F1/00(2006.01)n, C22F1/18(2006.01)n

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)

C22C14/00, C22F1/00, C22F1/18

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2016

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	JP 2014-1421 A (Kobe Steel, Ltd.), 09 January 2014 (09.01.2014), claims; examples & US 2013/0336835 A1 pages 4 to 6 & EP 2677052 A1 & KR 10-2013-0142080 A & CN 103509972 A	1, 3 2
X	JP 2009-299110 A (Kobe Steel, Ltd.), 24 December 2009 (24.12.2009), claims; examples & WO 2009/151031 A1 pages 7 to 14	1-3

☒ 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
06 May 2016 (06.05.16)Date of mailing of the international search report
17 May 2016 (17.05.16)Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/058247

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	JP 2012-52219 A (Kobe Steel, Ltd.), 15 March 2012 (15.03.2012), (Family: none)	1-3
A	JP 2007-239030 A (Daido Steel Co., Ltd.), 20 September 2007 (20.09.2007), (Family: none)	1-3
A	US 6053993 A (Oregon Metallurgical Corp.), 25 April 2000 (25.04.2000), & US 5861070 A	1-3

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REFERENCES CITED IN THE DESCRIPTION

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