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(54) TITANIUM ALLOY BAR AND METHOD FOR MANUFACTURING THE SAME

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(52) **U.S. Cl.** **420/420**; 148/670

(57) **ABSTRACT**

The invention relates to an $\alpha+\beta$ type titanium alloy bar consisting essentially of 4 to 5% Al, 2.5 to 3.5% V, 1.5 to 2.5% Fe, 1.5 to 2.5% Mo, by mass, and balance of Ti, and having 10 to 90% of volume fraction of primary α phase, 10 μm or less of average grain size of the primary α phase, and 4 or less of aspect ratio of the grain of the primary α phase on the cross sectional plane parallel in the rolling direction of the bar. The $\alpha+\beta$ type titanium alloy bar has excellent ductility, fatigue characteristics and formability.

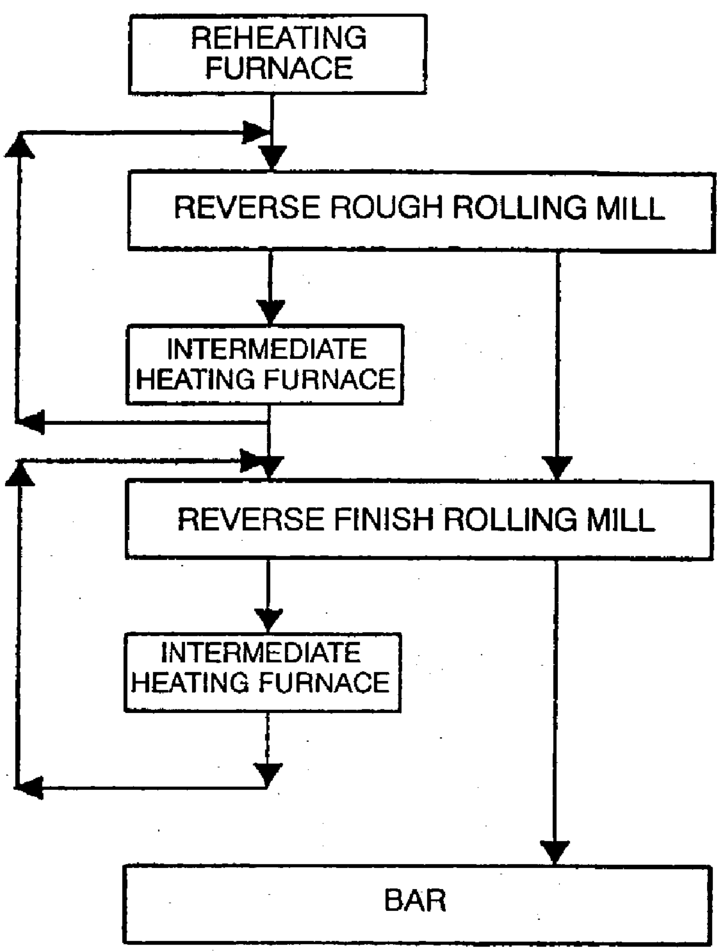


FIG. 1

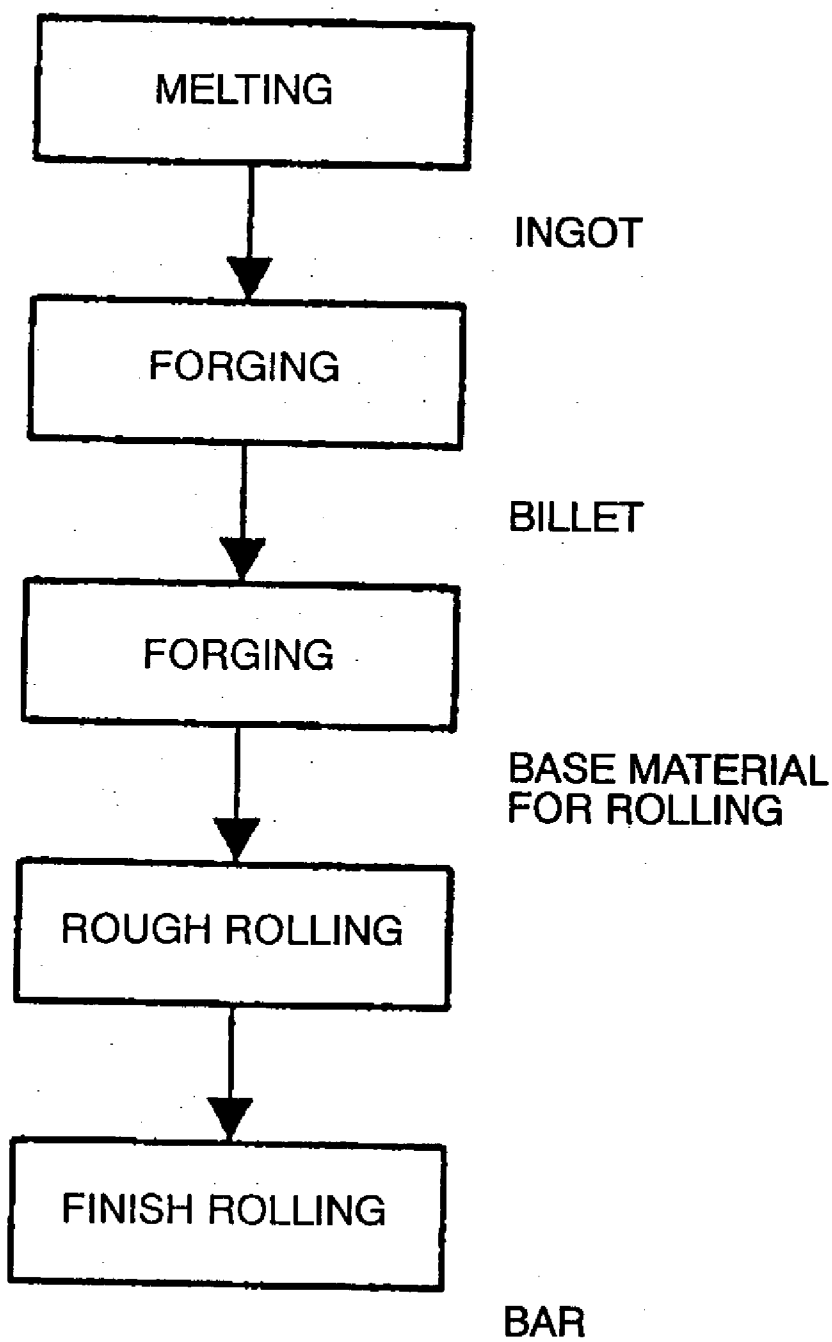

MELTING
INGOT
FORGING
BILLET
FORGING
BASE MATERIAL FOR ROLLING
ROUGH ROLLING
FINISH ROLLING
BAR

FIG. 2A

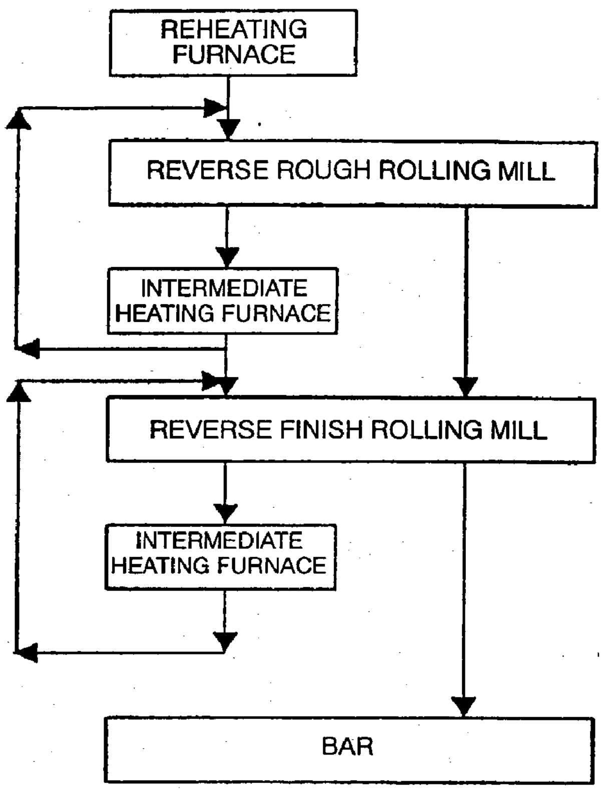

REHEATING FURNACE
REVERSE ROUGH ROLLING MILL
INTERMEDIATE HEATING FURNACE
REVERSE FINISH ROLLING MILL
INTERMEDIATE HEATING FURNACE
BAR

FIG. 2B

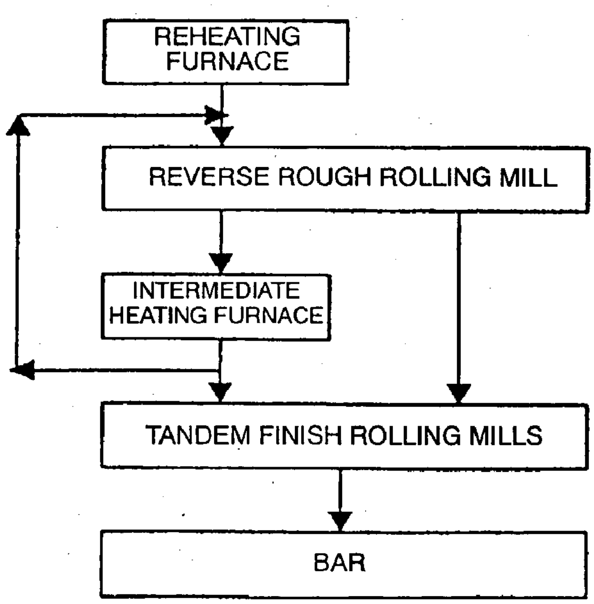

REHEATING FURNACE
REVERSE ROUGH ROLLING MILL
INTERMEDIATE HEATING FURNACE
TANDEM FINISH ROLLING MILLS
BAR

FIG. 3

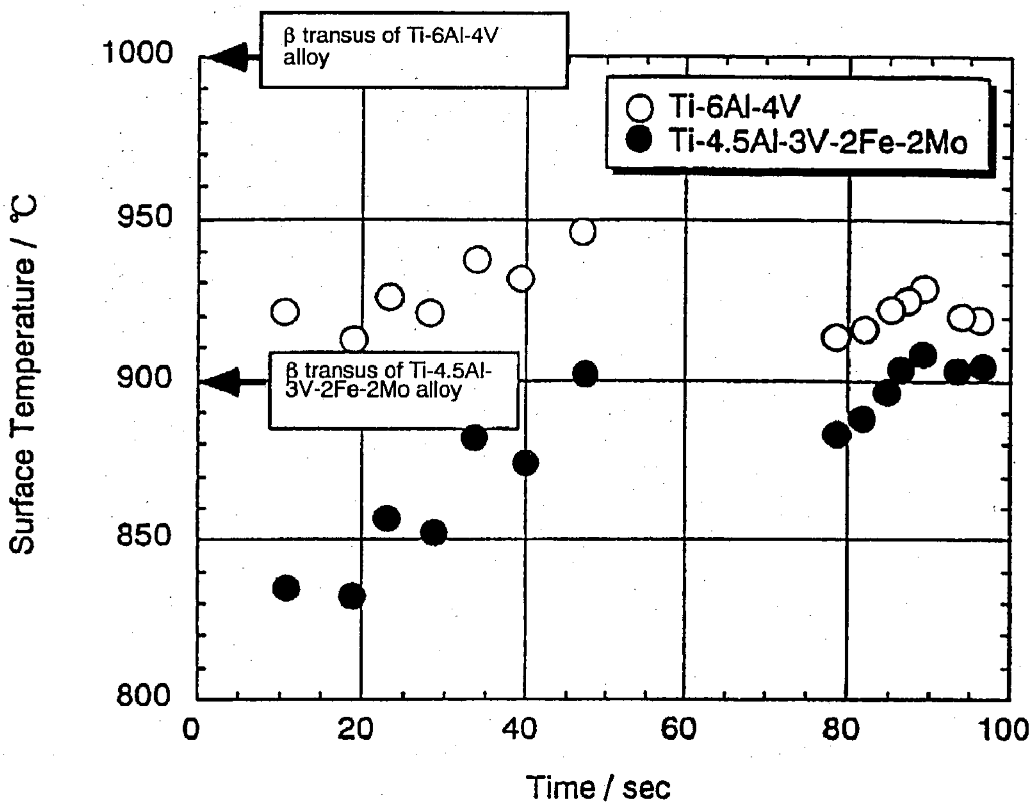

β transus of Ti-6Al-4V alloy
β transus of Ti-4.5Al-3V-2Fe-2Mo alloy
Ti-6Al-4V
Ti-4.5Al-3V-2Fe-2Mo
Surface Temperature / ℃
1000
950
900
850
800
0
20
40
60
80
100
Time / sec

FIG. 4

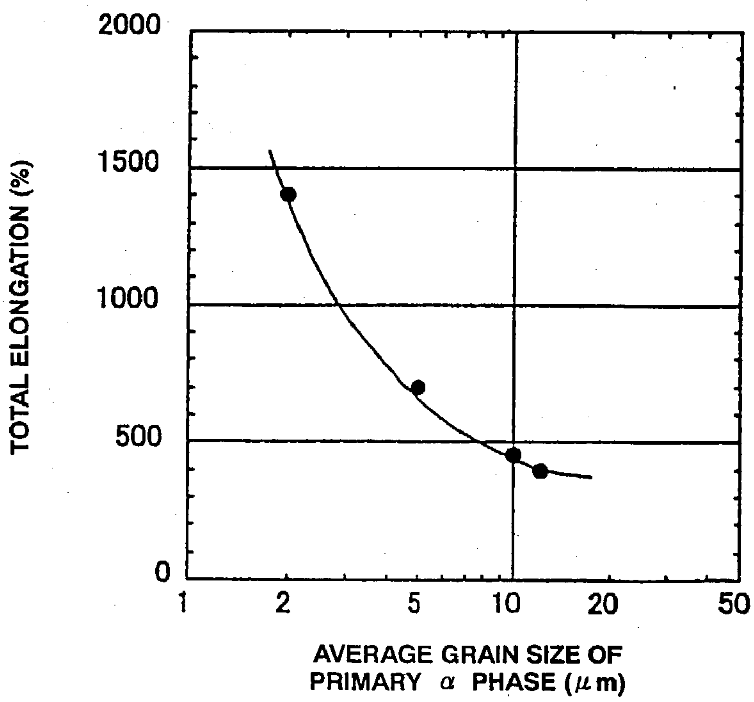

TOTAL ELONGATION (%)
2000
1500
1000
500
0
1
2
5
10
20
50
AVERAGE GRAIN SIZE OF PRIMARY α PHASE (μm)

FIG. 5

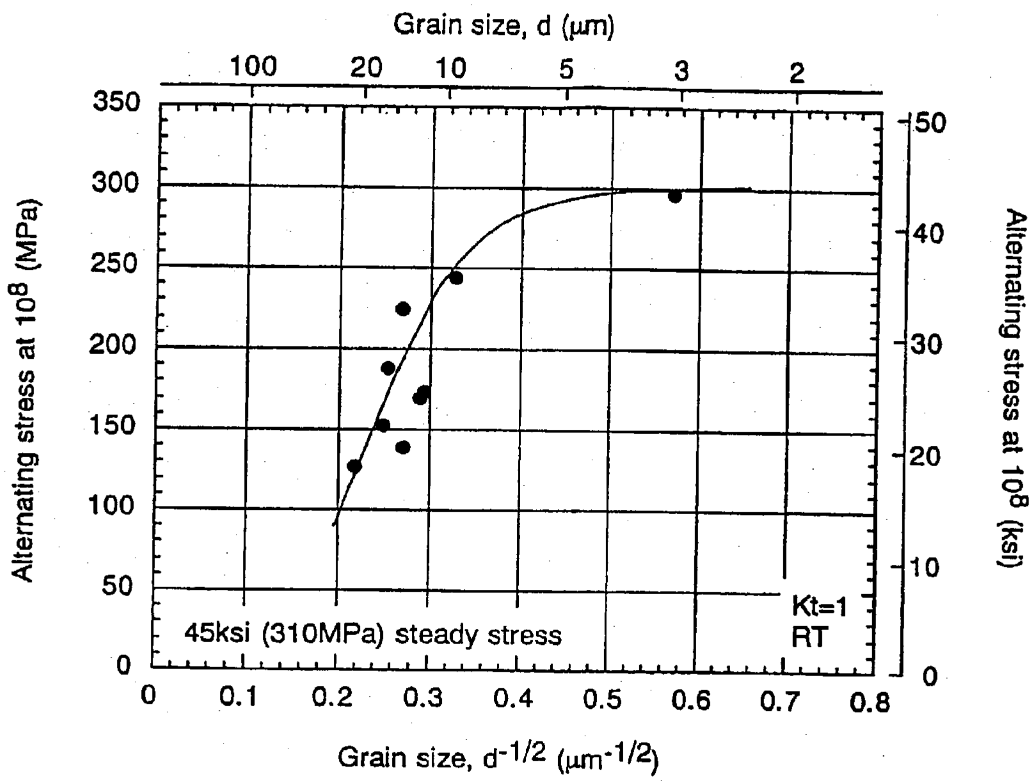

Grain size, d (μm)
100
20
10
5
3
2
350
300
250
200
150
100
50
0
Alternating stress at 10^8 (MPa)
50
40
30
20
10
0
Alternating stress at 10^8 (ksi)
45ksi (310MPa) steady stress
Kt=1
RT
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Grain size, d^-1/2 (μm^-1/2)

FIG. 6

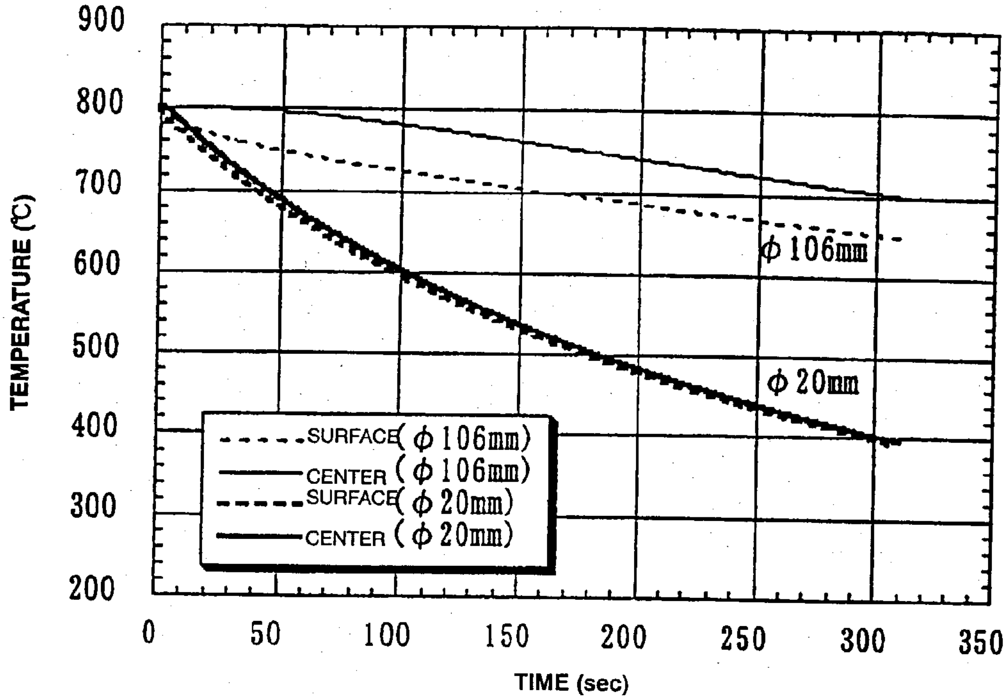
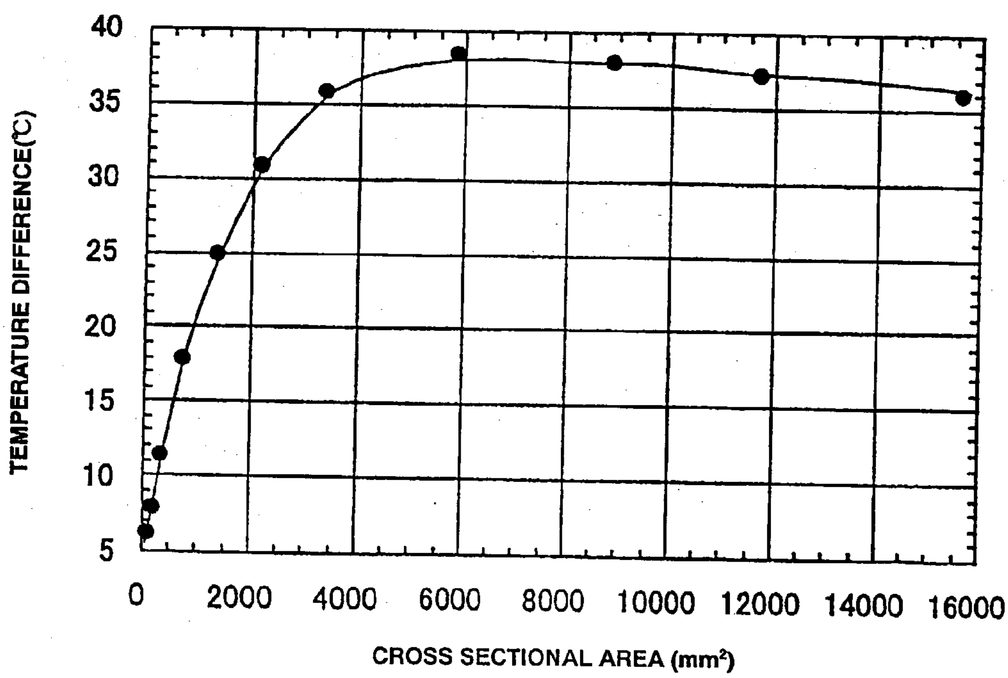

900
800
700
600
500
400
300
200
TEMPERATURE (℃)
φ 106mm
φ 20mm
SURFACE(φ 106mm)
CENTER (φ 106mm)
SURFACE(φ 20mm)
CENTER (φ 20mm)
0
50
100
150
200
250
300
350
TIME (sec)

FIG. 7


40
35
30
25
20
15
10
5
TEMPERATURE DIFFERENCE(℃)
0
2000
4000
6000
8000
10000
12000
14000
16000
CROSS SECTIONAL AREA (mm²)

TITANIUM ALLOY BAR AND METHOD FOR MANUFACTURING THE SAME

[0001] This application is a continuation application of International Application PCT/JP02/01710 (not published in English) filed Feb. 26, 2002.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to a titanium alloy bar having excellent ductility, fatigue characteristics and formability, particularly to an α+β type titanium alloy bar, and to a method for manufacturing thereof.

[0004] 2.Description of Related Arts

[0005] Owing to high strength, light weight and excellent corrosion resistance, titanium alloys are used as structural materials in the fields such as chemical plants, power generators, aircrafts and the like. Among them, an α+β type titanium alloy occupies a large percentage of use because of its high strength and relatively good formability.

[0006] Products made of titanium alloys have various shapes such as sheet, plate, bar and so on. The bar may be used as it is, or may be forged or formed in complex shapes such as a threaded fastener. Accordingly, the bar is requested to have excellent formability as well as superior ductility and fatigue characteristics.

[0007] **FIG. 1** shows a typical manufacturing method of bar.

[0008] An ingot prepared by melting is forged to a billet as a base material for hot rolling. As shown in **FIG. 2**A and **FIG. 2**B, the billet is hot rolled to a bar after reheated in a reheating furnace using a reverse rolling mill or tandem rolling mills. If necessary, the billet is intermediately reheated during hot rolling to compensate the temperature needed for subsequent hot rolling.

[0009] As for a titanium alloy bar, particularly as for an α+β type titanium alloy bar, however, the temperature of billet increases during hot rolling owing to the adiabatic heat, which disturbs stable hot rolling and manufacturing of a titanium alloy bar having excellent ductility, fatigue characteristics and formability. For example, if the temperature of billet increases to β transus or above, the finally hot rolled bar has β microstructure consisting mainly of acicular α phase, thus failing in attaining superior ductility and fatigue characteristics. In addition, even as for a Ti-6Al-4V alloy having high β transus, the increase in temperature during hot rolling owing to the adiabatic heat enhances grain growth, although the temperature during hot rolling hardly exceeds β transus, thus failing in attaining excellent ductility, fatigue characteristics and formability.

[0010] To solve the problem of temperature increase during hot rolling caused by the adiabatic heat, JP-A-59-82101, (the term "JP-A" referred herein signifies the "unexamined Japanese patent publication"), discloses a rolling method in which cross sectional area reduction rate of billet is specified to 40% or less per rolling pass in α region or in α+β region. JP-A-58-25465 discloses a method in which billet is water cooled during hot rolling to suppress the temperature rise caused by the adiabatic heat. Furthermore, Article 1 "Hot Bar Rolling of Ti-6Al-4V in a Continuous Mill (Titanium '92 Science and Technology)" describes that hot rolling speed is reduced to the lower limit of keeping performance of mill in order to suppress the adiabatic heat.

[0011] The methods disclosed in JP-A-59-82101 and JP-A-58-25465, however, cannot produce a titanium alloy bar that simultaneously has excellent ductility, fatigue characteristics and formability.

[0012] Even if cross sectional area reduction rate per rolling is 40% or less according to the method of JP-A-59-82102, it is not sufficient to suppress the adiabatic heat for some kinds of titanium alloys. The method of JP-A-58-25465 also causes characteristics deterioration by hydrogen absorption caused by water cooling, and difficulty in accurate temperature control because of deformation resulted from rapid cooling.

[0013] The method described in Article 1 deals with a Ti-6Al-4V alloy. As described below, the method is not necessarily applicable to alloys which generate large adiabatic heat and therefor should be hot rolled in low temperature region, resulting in poor ductility, fatigue characteristics and formability.

[0014] **FIG. 3** shows a relationship between temperature and rolling time during hot rolling for Ti-6Al-4V alloy and Ti-4.5Al-3V-2Fe-2Mo alloy.

[0015] The heating temperature was 950° C. for the Ti-6Al-4V alloy, and 850° C. for the Ti-4.5Al-3V-2Fe-2Mo alloy. The Ti-4.5Al-3V-2Fe-2Mo alloy has lower β transus than that of the Ti-6Al-4V alloy by 100° C. so that the heating temperature was reduced by the difference, thus selecting 850° C. as the heating temperature thereof. The rolling was conducted using a reverse rolling mill and tandem rolling mills, while selecting the same conditions of rolling speed, reduction rate and pass schedule to both alloys. The rolling speed of reverse rolling mill was 2.7 m/sec, and the rolling speed of tandem rolling mills was 2.25 m/sec at the final rolling pass where the rolling speed becomes the maximum for both alloys. The rolling speeds are lower than the rolling speed of Article 1 (6 m/sec). The cross sectional area reduction rate was selected to maximum 26% for both alloys.

[0016] For the case of the Ti-6Al-4V alloy, the rolling was conducted at a sufficiently lower temperature than 1000° C. which is the β transus of the alloy, thus giving favorable structure. For the case of the Ti-4.5Al-3V-2Fe-2Mo alloy, however, even if the heating temperature was decreased by the magnitude of low β transus, the low temperature rolling resulted in increased deformation resistance and in increased adiabatic heat, so the temperature increased to a temperature region exceeding the β transus, thus failed to obtain favorable microstructure. As a result, excellent ductility, fatigue characteristics and formability were not obtained. The result suggests that rolling conditions such as rolling temperature, reduction rate and time between rolling passes shall be considered, as well as the rolling speed.

SUMMARY OF THE INVENTION

[0017] An object of the present invention is to provide a high strength titanium alloy bar having excellent ductility, fatigue characteristics and formability, and to provide a method of manufacturing thereof.

[0018] The object is attained by an α+β type titanium alloy bar consisting essentially of 4 to 5% Al, 2.5 to 3.5% V, 1.5 to 2.5% Fe, 1.5 to 2.5% Mo, by mass, and balance of Ti, and having 10 to 90% of volume fraction of primary α phase, 10 μm or less of average grain size of the primary α phase, and 4 or less of aspect ratio of the grain of the primary α phase on the cross sectional plane parallel in the rolling direction of the bar.

[0019] The α+β type titanium alloy bar can be manufactured by a method comprising the step of hot rolling an α+β type titanium alloy consisting essentially of 4 to 5% Al, 2.5 to 3.5% V, 1.5 to 2.5% Fe, 1.5 to 2.5% Mo, by mass, and balance of Ti, while keeping the surface temperature thereof to β transus or below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] **FIG. 1** shows a typical method for manufacturing a bar.

[0021] **FIG. 2** shows a process for hot rolling a bar.

[0022] **FIG. 3** shows a relationship between temperature and rolling time during hot rolling for Ti-6Al-4V alloy and Ti-4.5Al-3V-2Fe-2Mo alloy.

[0023] **FIG. 4** shows a relationship between average grain size of primary α phase and total elongation measured by high temperature tensile test.

[0024] **FIG. 5** shows a relationship between average grain size of primary α phase and fatigue strength after 10^8 cycles observed in fatigue test.

[0025] **FIG. 6** shows temperature changes with time at surface and center.

[0026] **FIG. 7** shows a relationship between cross sectional area and temperature difference between surface and center.

DETAILED DESCRIPTION OF THE INVENTION

[0027] The inventors of the present invention studied the microstructure of α+β type titanium alloy bar to provide excellent ductility, fatigue characteristics and formability, and found the followings.

[0028] The α+β type titanium alloy consists of primary α phase and transformed β phase. If, however, the alloy contains very large volume fraction of α phase that has HCP structure having little sliding system, or contains very large volume fraction of transformed β phase containing acicular α phase, formability and ductility deteriorate. Consequently, the volume fraction of primary α phase is specified to a range of from 10 to 90%. If the volume fraction of α phase and of β phase is equal or close to each other at reheating stage before hot rolling, the formability becomes better, so the volume fraction of primary α phase is preferably between 50 and 80%.

[0029] **FIG. 4** shows a relationship between average grain size of primary α phase and total elongation measured by high temperature tensile test.

[0030] When the average grain size of primary α phase exceeds 10 μm, the total elongation measured by high temperature tensile test rapidly decreases, and therefore the formability degrades.

[0031] **FIG. 5** shows a relationship between average grain size of primary α phase and fatigue strength after 10^8 cycles observed in fatigue test.

[0032] If the average grain size of primary α phase exceeds 10 μm, the fatigue strength decreases. If the average grain size of primary α phase becomes less than 6 μm, higher fatigue strength is attained.

[0033] Forging a bar induces rough surface on a free deforming plane not contacting with a mold due to the shape of grains, or due to the aspect ratio of the grains. Generally, the grains of bar tend to be elongated in the rolling direction. Particularly for the case of upset forging, elongated grains appear on a side face of the bar that becomes a free deforming plane. Therefore, it is necessary to avoid excessive increase in the aspect ratio during forging, more concretely to regulate the aspect ratio not exceeding 4 for the grains of the primary α phase on a cross section parallel in the rolling direction of the bar in order to prevent rough surface on the bar after forged.

[0034] Based on the above-described findings, a high strength titanium alloy bar having excellent ductility, fatigue characteristics and formability is obtained when the volume fraction of the primary α phase is between 10 and 90%, preferably between 50 and 80%, the average grain size in the primary α phase is 10 μm or less, preferably 6 μm or less, and further the aspect ratio of grains in the primary α phase is 4 or less.

[0035] The α+β type titanium alloy bar having above-described microstructure should consist essentially of 4 to 5% Al, 2.5 to 3.5% V, 1.5 to 2.5% Fe, 1.5 to 2.5% Mo, by mass, and balance of Ti. The reasons to limit the content of individual elements are described below.

[0036] Al

[0037] Aluminum is an essential element to stabilize the α phase and to contribute to the strength increase. If the Al content is below 4%, high strength cannot fully be attained. If the Al content exceeds 5%, ductility degrades.

[0038] V

[0039] Vanadium is an element to stabilize the β phase and to contribute to the strength increase. If the V content is below 2.5%, high strength cannot fully be attained, and β phase becomes unstable. If the V content exceeds 3.5%, range of workable temperature becomes narrow caused by the lowered β transus, and cost increases.

[0040] Mo

[0041] Molybdenum is an element to stabilize the β phase and to contribute to the strength increase. If the Mo content is below 1.5%, high strength cannot fully be attained, and β phase becomes unstable. If the Mo content exceeds 2.5%, range of workable temperature becomes narrow-caused by the lowered β transus, and cost increases.

[0042] Fe

[0043] Iron is an element to stabilize the β phase and to contribute to the strength increase. Iron rapidly diffuses to improve formability. If, however, the Fe content is below 1.5%, high strength cannot fully be attained, and the β phase becomes unstable, which results in failing to attain excellent formability. If the Fe content exceeds 2.5%, range of workable temperature becomes narrow caused by the lowered β transus, and degradation in characteristics is induced by segregation.

[0044] The α+β type titanium alloy bar according to the present invention may be manufactured by hot rolling an α+β type titanium alloy having above-described composition while adjusting the conditions of heating temperature, rolling temperature range, reduction rate, rolling speed, time between passes, and other variables to suppress the temperature rise caused by the adiabatic g heat, namely to keep the surface temperature of the alloy not exceeding the β transus. For example, the method comprises the steps of: heating an α+β type titanium alloy having β transus of Tβ° C. so that the surface temperature ranges between (Tβ−150) and Tβ° C.; and hot rolling the heated α+β type titanium alloy so that the surface temperature thereof during hot rolling is between (Tβ−300) and (Tβ−50) ° C., and so that the finish surface temperature thereof is between (Tβ−300) and (Tβ−100) ° C.

[0045] The reason of heating the surface before hot rolling in the range of from (Tβ−150) to Tβ° C. is the following. If the surface temperature before hot rolling is below (Tβ−150) ° C., the decrease in temperature during the final rolling stage becomes significant to increase crack susceptibility and deformation resistance. And, if the surface temperature before hot rolling exceeds Tβ° C., the microstructure of the bar becomes β microstructure consisting mainly of acicular α phase, which deteriorates ductility and formability. The reason of limiting the surface temperature during hot rolling to the range of from (Tβ−300) to (Tβ−50) ° C. is the following. If the surface temperature during hot rolling is below (Tβ−300) ° C., the hot formability deteriorates to induce problems such as cracking. And, if the surface temperature during hot rolling exceeds (Tβ−50) ° C., the temperature rise caused by the adiabatic heat induces coarse grains and formation of acicular phase. The reason of limiting the finish surface temperature immediately after the final rolling pass to the range of from (Tβ−300) and (Tβ−100) ° C. is the following. If the finish temperature thereof is below (Tβ−300) ° C., the crack susceptibility and the deformation resistance increase. And, if the finish temperature thereof exceeds (Tβ−100) ° C., grains become coarse.

[0046] The hot rolling is conducted by plurality of rolling passes. To prevent temperature rise caused by the adiabatic heat, it is preferable to keep the reduction rate not more than 40% per rolling pass.

[0047] When the hot rolling is conducted by a reverse rolling mill, it is preferable to limit the rolling speed not more than 6 m/sec to prevent the temperature rise caused by the adiabatic heat. When the hot rolling is conducted by tandem rolling mills, it is preferable to limit the rolling speed not more than 1.5 m/sec.

[0048] Since the alloy is cooled from surface after each rolling pass, the surface of the alloy receives temperature drop to some extent before entering succeeding pass even if a temperature rise exists caused by the adiabatic heat. As shown in **FIG. 6**, however, if the alloy has a large diameter (for the case of 106 mm in diameter), the temperature drop at center section of the alloy is small so that a large temperature difference appears between the surface and the center of the alloy. When the temperature drop at the center is small, the alloy is subjected to succeeding rolling pass before lowering the temperature of the center, which further increases the temperature owing to the adiabatic heat. If the phenomenon sustains, the center is hot rolled at higher temperature than the initial temperature. Consequently, the center of alloy having large diameter is required to be cooled with sufficient time between rolling passes.

[0049] To this point, the inventors of the present invention made a detailed study on the temperature difference between the surface and the center, and derived the finding described below. As shown in **FIG. 7**, the temperature difference significantly increases at or above 3500 mm^2 of cross sectional area of alloy normal to the rolling direction thereof. When an alloy having large cross sectional area is hot rolled to S mm^2 of the cross sectional area, securing the time before entering succeeding rolling at $0.167\times S^{1/2}$ sec or more can make the temperature difference small and is favorable in manufacturing a bar having homogeneous characteristics.

[0050] According to the manufacturing method of the present invention, the hot rolling is carried out while keeping the surface temperature of the alloy to β transus or below, thus there is a possibility for the surface temperature to decrease to a lower than the required rolling temperature range during hot rolling depending on the time between rolling passes and on the diameter of alloy. In that case, reheating the alloy may be given using a high frequency heating unit or the like.

EXAMPLE 1

[0051] Materials having 125 square mm size were prepared by cutting each of the base alloy A01 (having composition within the range of the present invention) and the base alloy A02 (having composition outside the range of the present invention), both of which are α+β type titanium alloy having respective chemical compositions given in Table 1. The materials are hot rolled using a caliber rolling mill under respective conditions (B01 through B18) given in Table 2 to produce bars having 20 mm and 50 mm in diameter, respectively. For the time between rolling passes given in Table 2, ○ denotes the time between rolling passes of $0.167\times S^{1/2}$ or more for all the rolling passes under each rolling condition, and X denotes the time between rolling passes of less than $0.167\times S^{1/2}$. Table 3 through Table 20 give cross sectional area S of alloy, reduction rate, $0.167\times S^{1/2}$, time between rolling passes, surface temperature, and rolling speed on each rolling pass under each rolling condition. R in the table signifies a reverse rolling mill, and T signifies tandem rolling mills.

[0052] The produced bars were annealed at temperatures between 700 and 720° C. Tensile test was conducted to determine yield strength (0.2% PS), tensile strength (UTS), elongation (El), and reduction of area (RA). In addition, the smooth fatigue test (under the condition of Kt=1) and the notch fatigue test (under the condition of Kt=3) were given to determine fatigue strength.

[0053] Furthermore, optical microstructure examination was performed at the center of the bar and at the position of quarter of diameter (¼ D) to determine grain size of primary α phase, volume fraction of the grains, and aspect ratio of the grains on a cross section parallel in the rolling direction.

[0054] The results are given in Table 21. The columns of the microstructure in the table giving no grain size mean that the position consisted only of β microstructure consisting mainly of acicular α phase and that the equiaxed primary α phase could not be observed.

[0055] When the surface heating temperature is below (Tβ−150) ° C., the surface temperature of the alloy was excessively low, and the rolling load became excessive to fail in rolling. When the heating temperature exceeds Tβ° C., the surface temperature of the alloy became too high even if the time between rolling passes was within the range of the present invention, which is seen under the rolling conditions of B02 and B11, so the surface temperature exceeded Tβ° C. caused by the adiabatic heat to form β microstructure consisting mainly of acicular α phase at the center of the bar, thus deteriorated ductility and fatigue characteristics.

[0056] When the finish surface temperature was below (Tβ−300) ° C., the temperature of the alloy became too low, which deteriorated formability to generate cracks during hot rolling. When the finish surface temperature exceeded (Tβ−100) ° C., fine microstructure could not be attained, deteriorating ductility and fatigue characteristics as in the cases under the conditions of B04, B05, and B07.

[0057] When the surface temperature during hot rolling was below (Tβ−300) ° C., the surface temperature was too low, generating cracks. When the surface temperature exceeded (Tβ−50) ° C., the center and the ¼ D had β microstructure consisting mainly of acicular α phase after hot rolling, deteriorating ductility and fatigue characteristics.

[0058] When the reduction rate per rolling pass exceeded 40%, the adiabatic heat was enhanced, and the temperature of the alloy exceeded Tβ° C., and fine microstructure could not be attained.

[0059] In the case of the rolling condition B14 which applied a reverse rolling mill and which selected the rolling speeds of higher than 6 m/sec, or in the case of rolling condition B15 which applied tandem rolling mills and which selected the rolling speeds of higher than 1.5 m/sec, the adiabatic heat became large, and the surface temperature exceeded Tβ° C., thus failed to attain fine microstructure.

[0060] When the time between rolling passes was outside the range of the present invention, the surface temperature increase caused by the adiabatic heat overrode the temperature decrease caused by air cooling, thus the surface temperature exceeded Tβ° C., and fine microstructure could not be attained.

[0061] With the bars using A01 which had the chemical composition within the range of the present invention and produced under the rolling conditions B01, B06, B08, B09, B16, B17, and B18, homogeneous microstructure of 10 μm or smaller grain size of primary α phase was observed, and they provided excellent ductility and fatigue characteristics. That is, further excellent ductility and fatigue characteristics could be attained giving 15% or larger elongation, 40% or larger reduction of area, 500 MPa or larger smooth fatigue strength, and 200 MPa of notch (Kt=3) fatigue strength. Furthermore, with the α+β type titanium alloy bars having 50 to 80% of volume fraction of primary α phase and 6 μm or less of average grain size of primary α phase, produced under the rolling conditions of B01, B06, B08, and B09, further excellent ductility and fatigue characteristics could be attained giving 20% or larger elongation, 50% or larger reduction of area, 550 MPa or larger smooth fatigue strength, and 200 MPa of notch (Kt=3) fatigue strength.

[0062] On the other hand, bars produced using A02 having chemical composition outside the range of the present invention under the rolling conditions of B10 and B12 could not attain satisfactory ductility and fatigue characteristics because the grain size in the primary α phase exceeded 10 μm, though the adiabatic heat was suppressed because the rolling conditions were within the range of the present invention.

EXAMPLE 2

[0063] Cylindrical specimens having 8 mm in diameter and 12 mm in height were cut from the center section in radial direction of bars produced in Example 1 under the rolling conditions B01 through B18, respectively. The specimens were heated to 800° C. and were compressed to 70%. After the compression, the occurrence of cracks and of rough surface on the surface of each specimen was inspected to give evaluation of hot forging property.

[0064] The results are shown in Table 21.

[0065] As for the bars produced under the rolling conditions of B01, B06, B08, B09, B16, B17, and B18 which were within the range of the present invention, no crack and rough surface appeared, and favorable hot forging property was obtained.

[0066] On the other hand, for the bars produced under the rolling conditions of B10 and B12 in which the grain size in the primary α phase exceeded 10 μm, rough surface appeared, though no crack was generated. As for the bars having only α phase at center and ¼ D produced under the rolling conditions of B02, B03, B04, B05, B07, B11, B14, and B15, both cracks and rough surface appeared. Furthermore, for the bars produced under the rolling condition B14 giving aspect ratios of more than 4 for the grains in a cross section parallel in the rolling direction, though giving the grain size in the primary α phase and the volume fraction within the range of the present invention, rough surface also appeared.

TABLE 1

Alloy	Al	V	Fe	Mo	O	C	N	H	β transus
A01	4.7	3.1	2.1	1.9	0.1	0.001	0.005	0.0017	900° C.
A02	6.1	4.1	0.2	—	0.2	0.01	0.006	0.0016	1000° C.

Unit is mass %.

[0067]

TABLE 2

Rolling condition	Alloy	Finish diameter (mm)	Reheat-ing temp. (° C.)	Rolling temp. range (° C.)	Finish temp. (° C.)	Time between passes	Total number of passes	Maximum reduction rate per rolling pass (%)	Rolling speed in rough rolling (Reverse rolling mill) (m/sec)	Final rolling speed in finish rolling (Tandem rolling mills) (m/sec)	Remarks
B01	A01	φ20	800	700–811	714	○	17	25.8	2.7	1.125	E
B02	A01	φ20	950	755–929	765	○	17	25.8	2.7	1.125	C
B03	A01	φ20	890	754–911	764	○	17	25.8	2.7	1.125	C
B04	A01	φ20	850	818–930	919	○	8	42.4	2.7	1.125	C
B05	A01	φ20	800	845–901	865	X	17	25.8	2.7	1.125	C
B06	A01	φ50	800	711–804	731	○	12	18.4	2.7	1.125	E
B07	A01	φ50	830	864–909	874	X	12	18.4	2.7	1.125	C
B08	A01	φ20	800	670–812	690	○	17	25.8	2.7	1.125	E
B09	A01	φ20	820	721–829	726	○	17	25.8	2.7	1.125	E
B10	A02	φ20	900	791–887	806	○	17	25.8	2.7	1.125	C
B11	A02	φ20	1050	815–1024	825	○	17	25.8	2.7	1.125	C
B12	A02	φ50	900	810–906	830	○	12	18.4	2.7	1.125	C
B13	A01	φ20	920	698–928	698	○	17	25.8	2.7	1.125	C
B14	A01	φ20	800	774–911	774	○	17	25.8	10.8	1.125	C
B15	A01	φ20	800	719–910	864	○	17	25.8	2.7	2.250	C
B16	A01	φ50	830	764–845	766	○	12	18.4	2.7	1.125	E
B17	A01	φ20	830	757–842	777	○	17	25.8	2.7	1.125	E
B18	A01	φ20	865	772–850	772	○	17	25.8	2.7	1.125	E

E: Example,
C: Comparative example
Numerals with underline signify that they are outside the range of the present invention.

[0068]

TABLE 3

			Rolling condition: B01				
Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$0.167\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
	15625						
1	13000	16.8	19.0	25	2.7	790	R
2	11000	15.4	17.5	25	2.7	796	R
3	9500	13.6	16.3	25	2.7	801	R
4	8000	15.8	14.9	25	2.7	803	R
5	6500	18.8	13.5	25	2.7	811	R
6	5200	20.0	12.0	25	2.7	801	R
7	4150	20.2	10.8	25	2.7	779	R
8	3300	20.5	9.6	25	2.7	761	R
9	2450	25.8	8.3	25	2.7	738	R
10	1850	24.5	7.2	25	2.7	719	R
11	1450	21.6	6.4	5	0.350	721	T
12	1150	20.7	5.7	5	0.466	732	T
13	900	21.7	5.0	5	0.581	739	T
14	700	22.2	4.4	5	0.733	745	T
15	550	21.4	3.9	5	0.871	741	T
16	420	23.6	3.4	5	0.982	730	T
17	320	23.8			1.125	714	T

[0069]

TABLE 4

Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$0.167\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
			Rolling condition: B02				
	15625						
1	13000	16.8	19.0	25	2.7	929	R
2	11000	15.4	17.5	25	2.7	925	R
3	9500	13.6	16.3	25	2.7	919	R
4	8000	15.8	14.9	25	2.7	913	R
5	6500	18.8	13.5	25	2.7	911	R
6	5200	20.0	12.0	25	2.7	900	R
7	4150	20.2	10.8	25	2.7	891	R
8	3300	20.5	9.6	25	2.7	880	R
9	2450	25.8	8.3	25	2.7	868	R
10	1850	24.5	7.2	25	2.7	860	R
11	1450	21.6	6.4	5	0.350	852	T
12	1150	20.7	5.7	5	0.466	839	T
13	900	21.7	5.0	5	0.581	829	T
14	700	22.2	4.4	5	0.733	822	T
15	550	21.4	3.9	5	0.871	803	T
16	420	23.6	3.4	5	0.982	785	T
17	320	23.8			1.125	765	T

[0070]

TABLE 5

Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$0.167\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
			Rolling condition: B03				
	15625						
1	13000	16.8	19.0	25	2.7	890	R
2	11000	15.4	17.5	25	2.7	894	R
3	9500	13.6	16.3	25	2.7	899	R
4	8000	15.8	14.9	25	2.7	906	R
5	6500	18.8	13.5	25	2.7	911	R
6	5200	20.0	12.0	25	2.7	902	R
7	4150	20.2	10.8	25	2.7	889	R
8	3300	20.5	9.6	25	2.7	881	R
9	2450	25.8	8.3	25	2.7	867	R
10	1850	24.5	7.2	25	2.7	860	R
11	1450	21.6	6.4	5	0.350	852	T
12	1150	20.7	5.7	5	0.466	839	T
13	900	21.7	5.0	5	0.581	830	T
14	700	22.2	4.4	5	0.733	820	T
15	550	21.4	3.9	5	0.871	803	T
16	420	23.6	3.4	5	0.982	784	T
17	320	23.8			1.125	764	T

[0071]

TABLE 6

Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$0.167\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
			Rolling condition: B04				
	15625						
1	9300	40.5	19.0	25	2.7	849	R
2	5500	40.9	17.5	25	2.7	865	R

TABLE 6-continued

Rolling condition: B04

Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$0.167\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
3	3300	40.0	16.3	25	2.7	879	R
4	1900	42.4	14.9	25	2.7	896	R
5	1100	42.1	13.5	25	2.7	912	R
6	660	40.0	12.0	25	2.7	921	R
7	400	39.4	10.8	25	2.7	930	R
8	320	20.0			2.7	919	R

[0072]

TABLE 7

Rolling condition: B05

Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$0.167\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
	15625						
1	13000	16.8	19.0	10	2.7	791	R
2	11000	15.4	17.5	10	2.7	805	R
3	9500	13.6	16.3	10	2.7	819	R
4	8000	15.8	14.9	10	2.7	836	R
5	6500	18.8	13.5	10	2.7	850	R
6	5200	20.0	12.0	10	2.7	865	R
7	4150	20.2	10.8	10	2.7	871	R
8	3300	20.5	9.6	10	2.7	875	R
9	2450	25.8	8.3	10	2.7	879	R
10	1850	24.5	7.2	10	2.7	884	R
11	1450	21.6	6.4	5	0.350	901	T
12	1150	20.7	5.7	5	0.466	899	T
13	900	21.7	5.0	5	0.581	895	T
14	700	22.2	4.4	5	0.733	895	T
15	550	21.4	3.9	5	0.871	883	T
16	420	23.6	3.4	5	0.982	875	T
17	320	23.8			1.125	860	T

[0073]

TABLE 8

Rolling condition: B06

Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$0.167\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
	15625						
1	13000	16.8	19.0	25	2.7	791	R
2	11000	15.4	17.5	25	2.7	796	R
3	9500	13.6	16.3	25	2.7	801	R
4	8000	15.8	14.9	25	2.7	804	R
5	6700	16.3	13.7	25	2.7	806	R
6	6000	10.5	12.9	25	2.7	784	R
7	5200	13.3	12.0	25	2.7	764	R
8	4650	10.6	11.4	25	2.7	746	R
9	3800	18.3	10.3	25	2.7	733	R
10	3100	18.4	9.3	5	0.622	733	T
11	2600	16.1	8.5	5	0.837	734	T
12	2210	15.0			1.125	731	T

[0074]

TABLE 9

Rolling condition: B07							
Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$0.167\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
	15625						
1	13000	16.8	19.0	10	2.7	819	R
2	11000	15.4	17.5	10	2.7	836	R
3	9500	13.6	16.3	10	2.7	849	R
4	8000	15.8	14.9	10	2.7	873	R
5	6700	16.3	13.7	10	2.7	879	R
6	6000	10.5	12.9	10	2.7	896	R
7	5200	13.3	12.0	10	2.7	901	R
8	4650	10.6	11.4	10	2.7	904	R
9	3800	18.3	10.3	5	2.7	909	R
10	3100	18.4	9.3	5	0.622	902	T
11	2600	16.1	8.5	5	0.837	883	T
12	2210	15.0			1.125	874	T

[0075]

TABLE 10

Rolling condition: B08							
Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$0.167\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
	15625						
1	13000	16.8	19.0	25	2.7	790	R
2	11000	15.4	17.5	25	2.7	795	R
3	9500	13.6	16.3	25	2.7	799	R
4	8000	15.8	14.9	25	2.7	804	R
5	6500	18.8	13.5	25	2.7	812	R
6	5200	20.0	12.0	25	2.7	800	R
7	4150	20.2	10.8	25	2.7	780	R
8	3300	20.5	9.6	25	2.7	759	R
9	2450	25.8	8.3	25	2.7	741	R
10	1850	24.5	7.2	25	2.7	720	R
11	1450	21.6	6.4	10	0.350	719	T
12	1150	20.7	5.7	10	0.466	724	T
13	900	21.7	5.0	10	0.581	730	T
14	700	22.2	4.4	10	0.733	729	T
15	550	21.4	3.9	10	0.871	721	T
16	420	23.6	3.4	10	0.982	705	T
17	320	23.8			1.125	690	T

[0076]

TABLE 11

Rolling condition: B09							
Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
	15625						
1	13000	16.8	19.0	25	2.7	810	R
2	11000	15.4	17.5	25	2.7	816	R
3	9500	13.6	16.3	25	2.7	821	R
4	8000	15.8	14.9	25	2.7	824	R
5	6500	18.8	13.5	25	2.7	829	R
6	5200	20.0	12.0	25	2.7	821	R
7	4150	20.2	10.8	25	2.7	800	R

TABLE 11-continued

Rolling condition: B09

Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
8	3300	20.5	9.6	25	2.7	779	R
9	2450	25.8	8.3	25	2.7	761	R
10	1850	24.5	7.2	25	2.7	749	R
11	1450	21.6	6.4	5	0.350	741	T
12	1150	20.7	5.7	5	0.466	751	T
13	900	21.7	5.0	5	0.581	760	T
14	700	22.2	4.4	5	0.733	766	T
15	550	21.4	3.9	5	0.871	761	T
16	420	23.6	3.4	5	0.982	751	T
17	320	23.8			1.125	726	T

[0077]

TABLE 12

Rolling condition: B10

Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
	15625						
1	13000	16.8	19.0	25	2.7	886	R
2	11000	15.4	17.5	25	2.7	884	R
3	9500	13.6	16.3	25	2.7	884	R
4	8000	15.8	14.9	25	2.7	887	R
5	6500	18.8	13.5	25	2.7	885	R
6	5200	20.0	12.0	25	2.7	859	R
7	4150	20.2	10.8	25	2.7	841	R
8	3300	20.5	9.6	25	2.7	820	R
9	2450	25.8	8.3	25	2.7	800	R
10	1850	24.5	7.2	25	2.7	791	R
11	1450	21.6	6.4	5	0.350	801	T
12	1150	20.7	5.7	5	0.466	810	T
13	900	21.7	5.0	5	0.581	830	T
14	700	22.2	4.4	5	0.733	836	T
15	550	21.4	3.9	5	0.871	829	T
16	420	23.6	3.4	5	0.982	821	T
17	320	23.8			1.125	806	T

[0078]

TABLE 13

Rolling condition: B11

Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
	15625						
1	13000	16.8	19.0	25	2.7	1024	R
2	11000	15.4	17.5	25	2.7	1015	R
3	9500	13.6	16.3	25	2.7	1003	R
4	8000	15.8	14.9	25	2.7	996	R
5	6500	18.8	13.5	25	2.7	985	R
6	5200	20.0	12.0	25	2.7	969	R
7	4150	20.2	10.8	25	2.7	961	R
8	3300	20.5	9.6	25	2.7	949	R
9	2450	25.8	8.3	25	2.7	930	R
10	1850	24.5	7.2	25	2.7	921	R
11	1450	21.6	6.4	5	0.350	911	T
12	1150	20.7	5.7	5	0.466	901	T

TABLE 13-continued

Rolling condition: B11

Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
13	900	21.7	5.0	5	0.581	891	T
14	700	22.2	4.4	5	0.733	881	T
15	550	21.4	3.9	5	0.871	864	T
16	420	23.6	3.4	5	0.982	845	T
17	320	23.8			1.125	825	T

[0079]

TABLE 14

Rolling condition: B12

Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
	15625						
1	13000	16.8	19.0	25	2.7	891	R
2	11000	15.4	17.5	25	2.7	895	R
3	9500	13.6	16.3	25	2.7	899	R
4	8000	15.8	14.9	25	2.7	905	R
5	6700	16.3	13.7	25	2.7	906	R
6	6000	10.5	12.9	25	2.7	886	R
7	5200	13.3	12.0	25	2.7	865	R
8	4650	10.6	11.4	25	2.7	845	R
9	3800	18.3	10.3	25	2.7	836	R
10	3100	18.4	9.3	5	0.622	835	T
11	2600	16.1	8.5	5	0.837	834	T
12	2210	15.0			1.125	830	T

[0080]

TABLE 15

Rolling condition: B13

Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
	15625						
1	13000	16.8	19.0	25	2.7	929	R
2	11000	15.4	17.5	25	2.7	925	R
3	9500	13.6	16.3	25	2.7	919	R
4	8000	15.8	14.9	25	2.7	913	R
5	6500	18.8	13.5	25	2.7	911	R
6	5200	20.0	12.0	25	2.7	900	R
7	4150	20.2	10.8	25	2.7	891	R
8	3300	20.5	9.6	25	2.7	880	R
9	2450	25.8	8.3	25	2.7	868	R
10	1850	24.5	7.2	25	2.7	850	R
11	1450	21.6	6.4	10	0.350	832	T
12	1150	20.7	5.7	10	0.466	804	T
13	900	21.7	5.0	10	0.581	777	T
14	700	22.2	4.4	10	0.733	749	T
15	550	21.4	3.9	10	0.871	728	T
16	420	23.6	3.4	10	0.982	713	T
17	320	23.8			1.125	698	T

[0081]

TABLE 16

Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
	Rolling condition: B14						
	15625						
1	13000	16.8	19.0	25	10.8	810	R
2	11000	15.4	17.5	25	10.8	836	R
3	9500	13.6	16.3	25	10.8	861	R
4	8000	15.8	14.9	25	10.8	883	R
5	6500	18.8	13.5	25	10.8	911	R
6	5200	20.0	12.0	25	10.8	901	R
7	4150	20.2	10.8	25	10.8	869	R
8	3300	20.5	9.6	25	1.8	841	R
9	2450	25.8	8.3	25	10.8	808	R
10	1850	24.5	7.2	25	10.8	779	R
11	1450	21.6	6.4	10	0.350	781	T
12	1150	20.7	5.7	10	0.466	792	T
13	900	21.7	5.0	10	0.581	799	T
14	700	22.2	4.4	10	0.733	805	T
15	550	21.4	3.9	10	0.871	801	T
16	420	23.6	3.4	10	0.982	790	T
17	320	23.8			1.125	774	T

[0082]

TABLE 17

Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
	Rolling condition: B15						
	15625						
1	13000	16.8	19.0	25	2.7	790	R
2	11000	15.4	17.5	25	2.7	796	R
3	9500	13.6	16.3	25	2.7	801	R
4	8000	15.8	14.9	25	2.7	803	R
5	6500	18.8	13.5	25	2.7	811	R
6	5200	20.0	12.0	25	2.7	801	R
7	4150	20.2	10.8	25	2.7	779	R
8	3300	20.5	9.6	25	2.7	761	R
9	2450	25.8	8.3	25	2.7	738	R
10	1850	24.5	7.2	25	2.7	719	R
11	1450	21.6	6.4	5	0.700	751	T
12	1150	20.7	5.7	5	0.932	782	T
13	900	21.7	5.0	5	1.162	829	T
14	700	22.2	4.4	5	1.466	865	T
15	550	21.4	3.9	5	1.742	891	T
16	420	23.6	3.4	5	1.964	910	T
17	320	23.8			1.500	864	T

[0083]

TABLE 18

Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
	Rolling condition: B16						
	15625						
1	13000	16.8	19.0	25	2.7	821	R
2	11000	15.4	17.5	25	2.7	817	R

TABLE 18-continued

Rolling condition: B16

Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
3	9500	13.6	16.3	25	2.7	834	R
4	8000	15.8	14.9	25	2.7	838	R
5	6700	16.3	13.7	25	2.7	845	R
6	6000	10.5	12.9	25	2.7	824	R
7	5200	13.3	12.0	25	2.7	794	R
8	4650	10.6	11.4	25	2.7	776	R
9	3800	18.3	10.3	25	2.7	767	R
10	3100	18.4	9.3	5	0.622	764	T
11	2600	16.1	8.5	5	0.837	769	T
12	2210	15.0			1.125	766	T

[0084]

TABLE 19

Rolling condition: B17

Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$0.167\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
	15625						
1	13000	16.8	19.0	25	2.7	822	R
2	11000	15.4	17.5	25	2.7	825	R
3	9500	13.6	16.3	25	2.7	833	R
4	8000	15.8	14.9	25	2.7	834	R
5	6500	18.8	13.5	25	2.7	842	R
6	5200	20.0	12.0	25	2.7	830	R
7	4150	20.2	10.8	25	2.7	809	R
8	3300	20.5	9.6	25	2.7	790	R
9	2450	25.8	8.3	25	2.7	765	R
10	1850	24.5	7.2	25	2.7	757	R
11	1450	21.6	6.4	5	0.350	759	T
12	1150	20.7	5.7	5	0.466	772	T
13	900	21.7	5.0	5	0.581	771	T
14	700	22.2	4.4	5	0.733	774	T
15	550	21.4	3.9	5	0.871	771	T
16	420	23.6	3.4	5	0.982	779	T
17	320	23.8			1.125	777	T

[0085]

TABLE 18

Rolling condition: B18

Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	$\sqrt{\sqrt{S}}$ (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
	15625						
1	13000	16.8	19.0	25	2.7	850	R
2	11000	15.4	17.5	25	2.7	847	R
3	9500	13.6	16.3	25	2.7	847	R
4	8000	15.8	14.9	25	2.7	845	R
5	6500	18.8	13.5	25	2.7	844	R
6	5200	20.0	12.0	25	2.7	845	R
7	4150	20.2	10.8	25	2.7	843	R
8	3300	20.5	9.6	25	2.7	834	R
9	2450	25.8	8.3	25	2.7	830	R
10	1850	24.5	7.2	25	2.7	829	R
11	1450	21.6	6.4	5	0.350	821	T
12	1150	20.7	5.7	5	0.466	814	T

TABLE 18-continued

Rolling condition: B18							
Number of passes	Cross sectional area (mm^2)	Reduction rate (*)	√√S (sec)	Time between passes (sec)	Rolling speed (m/sec)	Temp. (° C.)	Rolling mill
13	900	21.7	5.0	5	0.581	803	T
14	700	22.2	4.4	5	0.733	794	T
15	550	21.4	3.9	5	0.871	790	T
16	420	23.6	3.4	5	0.982	782	T
17	320	23.8			1.125	772	T

[0086]

TABLE 21

					Fatigue strength		Microstructure (primary α)						Forging characteristics		
							1/4D			Center section					
Rolling condition	0.2% PS (MPa)	UTS (MPa)	E1 (%)	RA (%)	Smooth test (Kt = 1)	Notch test (Kt = 3)	Grain size (μm)	Volume fraction (%)	Aspect ratio	Grain size (μm)	Volume fraction (%)	Aspect ratio	Occurrence of crack	Occurrence of rough surface	Remark
B01	931	1030	20.4	51.9	565	230	2.5	66	1.5	2.7	66	1.8	Not occurred	Not occurred	E
B02	885	1009	3.5	12.3	350	120	3.7	59	4.1	—	—	—	Occurred	Occurred	C
B03	879	1010	4.1	13.5	355	125	3.4	58	4.4	—	—	—	Occurred	Occurred	C
B04	881	1011	4.1	11.6	365	115	—	—	—	—	—	—	Occurred	Occurred	C
B05	874	1014	3.8	11.1	360	100	3.8	29	4.2	—	—	—	Occurred	Occurred	C
B06	921	1020	20.0	50.8	560	225	5.4	60	2.1	5.8	68	2.2	Not occurred	Not occurred	E
B07	887	1005	3.7	12.1	355	120	5.9	31	4.3	—	—	—	Occurred	Occurred	C
B08	930	1030	20.5	52.3	570	240	1.7	67	1.9	1.9	69	2.3	Not occurred	Not occurred	E
B09	929	1027	20.1	50.1	550	210	4.1	62	1.7	4.9	64	2.1	Not occurred	Not occurred	E
B10	911	1019	14.8	43.3	480	185	11.4	89	2.8	12.0	88	3.2	Not occurred	Occurred	C
B11	863	1012	3.6	9.8	230	95	13.2	85	2.9	—	—	—	Occurred	Occurred	C
B12	902	1011	13.8	42.1	440	175	14.5	80	3.0	15.0	89	3.4	Not occurred	Occurred	C
B13	899	987	12.1	38.2	395	155	5.5	85	4.2	5.8	87	4.5 Not	Occurred occurred	C	
B14	884	971	13.7	34.5	345	115	5.2	84	4.2	—	—	—	Occurred	Occurred	C
B15	894	955	11.9	33.3	340	120	5.3	81	4.3	—	—	—	Occurred	Occurred	C
B16	910	1014	17.4	40.1	505	205	6.2	63	2.5	6.4	60	2.7	Not occurred	Not occurred	E
B17	914	1021	18.3	42.3	510	205	5.8	64	2.7	6.3	61	2.9	Not occurred	Not occurred	E
B18	902	1008	15.6	40.1	500	200	6.5	60	3.1	6.6	60	3.3	Not occurred	Not occurred	E

E: Example,

C: Comparative example

What is claimed:

1. An α+β type titanium alloy bar consisting essentially of 4 to 5% Al, 2.5 to 3.5% V, 1.5 to 2.5% Fe, 1.5 to 2.5% Mo, by mass, and balance of Ti, and having 10 to 90% of volume fraction of primary α phase, 10 μm or less of average grain size of the primary α phase, and 4 or less of aspect ratio of the grain of the primary α phase on the cross sectional plane parallel in the rolling direction of the bar.

2. The α+β type titanium alloy bar of claim 1, wherein the volume fraction of primary α phase is 50 to 80%, and the average grain size of the primary α phase is 6 μm or less.

3. A method for manufacturing an α+β type titanium alloy bar comprising the step of hot rolling an α+β type titanium alloy consisting essentially of 4 to 5% Al, 2.5 to 3.5% V, 1.5 to 2.5% Fe, 1.5 to 2.5% Mo, by mass, and balance of Ti, while keeping the surface temperature thereof to β transus or below.

4. The method for manufacturing an α+β type titanium alloy bar of claim 3 comprising the steps of: heating an α+β type titanium alloy having a β transus of Tβ° C. while keeping the surface temperature thereof between (Tβ−150) and Tβ° C.; and hot rolling the heated α+β type titanium alloy while keeping the surface temperature thereof during hot rolling between (Tβ−300) and (Tβ−50) ° C. and keeping the finish surface temperature thereof, as the surface temperature immediately after the final rolling pass, between (Tβ−300) and (Tβ−100) ° C.

5. The method for manufacturing an α+β type titanium alloy bar of claim 4, wherein the α+β type titanium alloy is hot rolled at a reduction rate of 40% or less per rolling pass.

6. The method for manufacturing an α+β type titanium alloy bar of claim 4, wherein the rolling speed is selected to 6 m/sec or less when a reverse rolling mill is applied to hot rolling.

7. The method for manufacturing an α+β type titanium alloy bar of claim 4, wherein the rolling speed is selected to 1.5 m/sec or less when tandem rolling mills are applied to hot rolling.

8. The method for manufacturing an α+β type titanium alloy bar of claim 4, wherein when the α+β type titanium alloy having 3500 mm^2 or larger cross sectional area in normal to the rolling direction is hot rolled to the cross sectional area of S mm^2, a waiting time before starting succeeding rolling is $0.167 \times S^{1/2}$ or more sec.

9. The method for manufacturing an α+β type titanium alloy bar of claim 4, wherein the α+β type titanium alloy is reheated during hot rolling.

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